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The Stress–weight Interface in Metre

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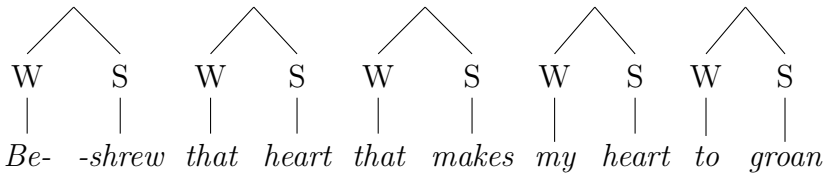
The stress-weight interface in meter*

Abstract

Meters are typically classified as being accentual (mapping stress, as in English) or quantitative (mapping weight, as in Sanskrit). This article treats the less well-studied typology of hybrid accentual-quantitative meters, which fall into two classes. In the first, stress and weight map independently onto the same meter, as attested in Latin and Old Norse. In the second, stress and weight interact, such that weight is regulated more strictly for stressed than unstressed syllables, as illustrated here by new analyses of Dravidian and Finno-Ugric meters. In both of these latter cases (as well as in Serbo-Croatian), strictness of weight mapping is modulated gradiently by stress level.

Among poetic meters regulating the properties of syllables, two types are traditionally distinguished, namely, accentual (regulating stress or pitch accent placement, as in English) and quantitative (regulating weight, as in Sanskrit).[1] Meters are here assumed, with perhaps most research in generative metrics, to be abstract trees of strong (S) and weak (W) nodes (see Blumenfeld 2016 for an overview).[2] For example, a line of English iambic pentameter is given with its terminal layer of S and W nodes in (1) (cf. Hayes 1988:222, Hayes et al. 2012:697). The concern of this article is not the generation of these structures (see e.g. Hanson and Kiparsky 1996), but the principles of PROMINENCE MAPPING (or correspondence; Blumenfeld 2015) that regulate how S and W nodes are realized by linguistic material.

(1) (Sonnet 133)



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[1]Additionally, tonal sequencing in verse may exhibit metrical properties, as in Chinese (Hayes 1988:225f, Fabb and Halle 2008:254ff). Moreover, not all meters regulate properties of syllables; cf. e.g. so-called syllable- or mora-counting meters (Dresher and Friedberg 2006).

[2]The framework for generative metrics employed here is termed the 'modular template-matching approach' by Kiparsky (to appear). On this approach, constraints regulate the correspondence between an abstract poetic meter (tree or bracketed grid) and the phonological material instantiating it. Some recent work within this approach, all assuming S/W trees (or, in Blumenfeld 2015, a notational variant), includes Blumenfeld (2015, 2016), Deo (2007), Deo and Kiparsky (2011), Hanson (2006, 2009a, 2009b), Hayes and Moore-Cantwell (2011), Hayes et al. (2012), Kiparsky (to appear), among others. Other approaches to generative metrics involve bottom-up parsing (Fabb and Halle 2008) or non-modularity (Golston 1998, Golston and Riad 2000, 2005); see Blumenfeld (2015, 2016), Hayes (2010), and Kiparsky (to appear) for recent further discussion of framework-level issues.

In an accentual meter, mapping relates meter to stress or phonological strength. For example, strong positions might be required to be stressed (notated STRONG⇒STRESS), or weak positions unstressed (STRESS⇒STRONG). When both conditions hold, these constraints can be combined into the biconditional STRONG⇔STRESS, as in (2).[3] This is the simplest possible stress-mapping principle, though most accentual meters require more analytical nuance. For example, Hayes et al. (2012:697) estimate that only 12% of Shakespeare's lines adhere to STRONG⇔STRESS as rigidly as examples like (1) do. Thus, STRONG⇔STRESS is mentioned here only as a kind of general schema to represent the meter-stress interface; see §1.2–2.2 for some refinements of it that are necessary to analyze real meters. Similarly, in a quantitative meter, mapping relates meter to weight, most simply via STRONG⇔HEAVY, as in (3).

(2) STRONG⇔STRESS: A metrically strong position must contain a stressed syllable, and a stressed syllable must be metrically strong.

(3) STRONG⇔HEAVY: A metrically strong position must contain a heavy syllable, and a heavy syllable must be metrically strong.

Many meters exhibit either stress-mapping or weight-mapping, but not both. For example, Arabic, Sanskrit, and Ancient Greek meters are said to be quantitative, while the English iambic pentameter is said to be accentual. To be sure, some constraints used to analyze the iambic pentameter refer to weight. For example, some poets permit a position to be filled by two syllables iff the first is light and they occupy the same word. This license, however, does not concern prominence mapping, but rather position size (on this distinction, see Hanson and Kiparsky 1996:299). Furthermore, different meters within the same language might employ different types of mapping. Some English poets, for instance, employ quantitative meter (e.g. Sir Philip Sidney; Hanson 2001).

This article addresses hybrid accentual-quantitative meters, which feature both stress- and weight-mapping. These meters fall into two classes, as schematized in Figure (1). In the first, termed INDEPENDENT MAPPING, stress and weight interface separately with the same meter. For example, perhaps the most well-known quantitative meter is the Latin hexameter. But this meter is not purely quantitative, as sometimes suggested: For most authors of the Augustan and later periods, including Virgil, Ovid, and several others (§1.1), the cadence of the line exhibits virtually strict stress-mapping alongside weight-mapping. In the Latin hexameter, then, as with Old Norse (§1.3), weight-mapping (STRONG⇔HEAVY) and stress-mapping (STRONG⇔STRESS) coexist. Crucially, both refer to the same underlying meter; the situation is not one of simultaneous meters. If a position is strong for weight, it must also be strong for stress, and vice versa. Previous proposals to the effect that stress and meter actively clash in parts of the line, implicating unnatural STRONG⇔¬STRESS or else

[3] In this article, a biconditional constraint such as $p \Leftrightarrow q$ can be interpreted as a notational placeholder for two constraints (in this case, $p \Rightarrow q$ and $q \Rightarrow p$) ranked (or weighted) in the same place. See §3 for further discussion of the conditional formalism and its typology.

disjunct meters, are argued in §1.1 to be premature.

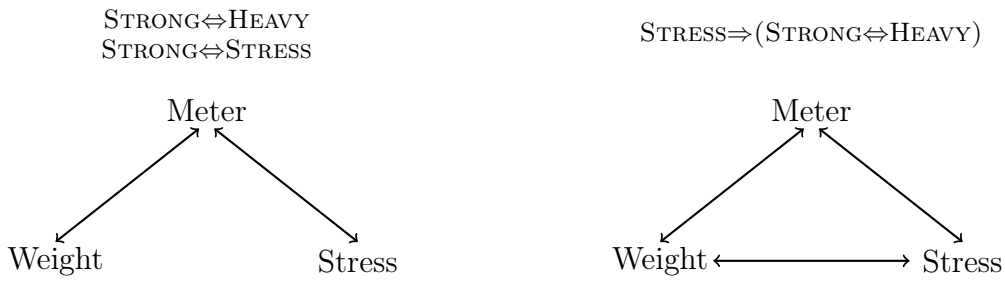


Figure 1: Two types of hybrid accentual-quantitative meter, namely, independent mapping (left) and interactive mapping (right).

The second type of hybrid accentual-quantitative meter is INTERACTIVE MAPPING. These meters are also quantitative, but quantity is regulated more strictly for stressed than unstressed syllables. In other words, weight-mapping is modulated by stress level, as encoded here by constraints of the form STRESS⇒(STRONG⇔HEAVY), as in (4). See §3 for truth tables and discussion of why other logically possible combinations of these predicates, such as weight-modulated stress-mapping, may be unattested.

(4) STRESS⇒(STRONG⇔HEAVY): If a syllable is stressed, it must be heavy in a strong position and light in a weak position.

Two genealogically unrelated cases of interactive mapping are examined in detail. First, weight-mapping in a medieval Tamil quantitative meter is shown in §2.1 to be nearly categorical for stressed syllables, but looser for unstressed syllables, though not ignored altogether. The second case comes from Kalevala Finnish (§2.2). As previously described, weight-mapping in the Kalevala applies only to primary-stressed syllables. This description is revised here, as it is demonstrated that secondary-stressed and unstressed syllables are also preferentially weight-mapped, albeit to lesser degrees, scaling with stress level. Yet a third genealogically unrelated case of interactive mapping is the Serbo-Croatian epic decasyllable, which is not analyzed here (see Jakobson 1933, 1952, Hayes 1988, Zec 2009). Jakobson (1952:418f) describes weight-mapping as applying more stringently for stressed than unstressed syllables, though it operates at least as a tendency for both. In short, in every documented case of interactive mapping, weight-mapping scales gradiently with stress level. This generalization has not been previously recognized, nor has gradient stress-modulation been previously formalized. Explanations for the typology of possible and impossible interfaces are proposed in §3, before concluding in §4.

1 Independent stress- and weight-mapping

In a language with both stress and distinctive quantity, an individual meter can regulate both of these properties. This section examines two such cases in detail, namely, the Latin

hexameter (as employed by Virgil) and the Old Norse *dróttkvætt*. In §1.1, it is shown that the hexameter regulates stress, but only in the cadence. Against previous accounts of Latin, it is argued that there was probably no explicit tendency for stress to clash with the meter outside of the cadence, and therefore no need to invoke a counter-universal constraint of the type STRONG⇒¬STRESS. The Latin hexameter is then analyzed in §1.2 using independent stress-meter and weight-meter interface constraints. For Latin, as for Old Norse in §1.3, stress-mapping and weight-mapping need not interact with each other, though both must answer to the same abstract meter, that is, arrangement of strong and weak positions.

1.1 The Latin hexameter: stress regulation

The Latin dactylic hexameter, like its Greek predecessor, follows the descriptive template in (5), exemplified in (6) (Raven 1965, Duckworth 1969, Halle 1970, Halporn et al. 1980, Prince 1989, Boldrini 1999). Each of the six metrical feet comprises two positions: First, the strong position ('S'; also known as the princeps or thesis) must be filled by a heavy syllable (notated –). Second, the weak position ('W'; also known as the biceps or arsis) can be filled by either a single heavy or a pair of lights (⏑⏑), except in the final foot, where W is a single syllable of any weight. A syllable is light iff it ends with a short vowel. The fifth weak position shows – in parentheses because this option is rarely employed; in Virgil, it accounts for fewer than 1% of lines. Caesura usually falls within the third foot; in Virgil, ∼85% of main caesurae fall immediately after the third strong position.

(5)

Foot 1		Foot 2		Foot 3		Foot 4		Foot 5		Foot 6	
S	W	S	W	S	W	S	W	S	W	S	W
–	{ – / ⏑⏑ }	–	{ – / ⏑⏑ }	–	{ – / ⏑⏑ }	–	{ – / ⏑⏑ }	–	{ (–) / ⏑⏑ }	–	{ – / ⏑ }

(6) $|_1$*ár.ma* *.vi*$|_2$*rúm.que* *.cá*$|_3$*nō,* *.trṓ*$|_4$*iae* *.quī* $|_5$*prī́.mu.s* *a*$|_6$*b* *ṓ.rīs*

Unlike Ancient Greek, Latin has salient word stress. While stress is often glossed over in introductions to the hexameter, the Latin hexameter is widely regarded to be sensitive to stress in addition to weight. In particular, in the final two feet (referred to here as the CADENCE), strong positions are nearly always stressed, and weak positions unstressed.[4] Elsewhere, stress alignment with the meter is looser, perhaps even actively avoided in the middle of the line (e.g. Sturtevant 1919:383, 1923a, Knight 1931, 1939/1950, Wilkinson 1963, Allen 1973:335ff, Coleman 1999:30, Ross 2007:143ff), though see below for an argument against active avoidance. The frequent clashes in the middle of the line are often regarded as setting up a tension that is resolved by the regular cadence.

Figure 2 depicts the alignment of stress and meter across the Latin hexameter line. The corpus is the first six books of Virgil's *Aeneid* (c. 25 BCE), with macrons following

[4]The cadence is sometimes also termed the CLAUSULA. It might also be identified as the final colon of the line (see §1.2).

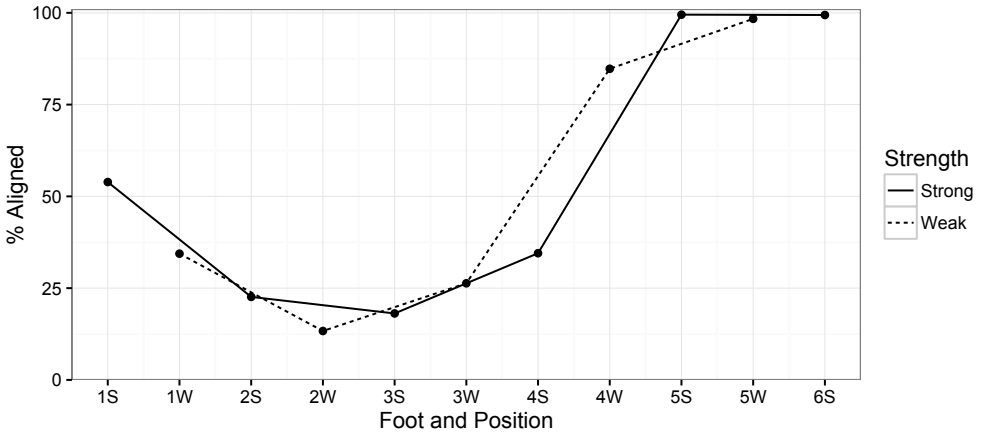


Figure 2: Percentage of alignment across the Latin hexameter line (except 6W; see text). Strong and weak positions are separated. For example, '4W' is the weak position of the fourth foot.

Pharr (1964). All statistics for 'Virgil' below should be understood to refer only to this subcorpus of Virgil.[5] A Perl program was employed to annotate syllables for stress and metrical position.[6] Due to irrelevant complications such as irregular line or vowel length, or to the variable phenomena mentioned in footnote 6, the program did not succeed in scanning every line. Lines that failed to scan were excluded, reducing the corpus by 13%. The final scanned corpus contains 4,045 lines.

Alignment in Figure 2 is defined as follows. A strong position is aligned (also known as HARMONIC or HOMODYNED [sic]; Sturtevant 1923a, Knight 1950) iff it contains a stressed syllable, and a weak position is aligned iff it does not contain one. For simplicity, monosyllabic words, which are usually function words, were treated as neither stressed nor unstressed (Sturtevant 1923a makes the same exclusion). If a position contained nothing but one or more monosyllables, it was ignored (i.e. counted as neither aligned nor non-aligned). If a weak position included one monosyllable and one (part of a) non-monosyllable, it was evaluated according to the rule above, ignoring the monosyllable portion of the position. For

[5]Though this section focuses on Virgil's *Aeneid* as a case study of noninteractive hybrid mapping, the cadence was treated similarly by most Latin hexameter poets (with the greatest outlier being Ennius, the earliest among them). Sturtevant (1923a:57ff) reports the rates of stress alignment in the hexameter cadence for 13 Latin poets, concluding that 'the requirement gradually became more rigid from Ennius, who has 92.8 per cent of harmony, to Vergil, who has 99.4 per cent of harmony. In imperial times only the satirists show less than 99 per cent of harmony.' Other authors with over 99% alignment in the cadence include Ovid, Lucan, Statius, and Silius Italicus. But of all 13 poets examined, none has a rate lower than Ennius's 92.8%. Meanwhile, the remainder of the line exhibits an alignment rate of 30–50% across all poets, in sharp contradistinction to the cadence. At any rate, the representativeness of Virgil is irrelevant here, as the purpose of the case study is to instantiate a metrical type, not to encapsulate a Latin verse tradition.

[6]Stress was assigned on a word-by-word basis, prior to applying elision. Because the situation with secondary stress is unclear (e.g. Sturtevant 1923a:55), only primary stress was analyzed. Stress of encliticized words followed the recommendation of Newcomer (1908:153) for Virgil, whereby the clitic is prestressing, except when immediately preceded by a light (e.g. *ítaque*, *scéleraque*). *Muta cum liquida* tautosyllabification and elision, being norms, were applied universally by the parser, one source of scansion failures.

example, the cadence of the *Aeneid*'s opening line (see (6)) is *prī́mus ab ṓrīs*. Because *ab* is ignored here for stress assignment, every position in this cadence is considered aligned.

One final caveat about this treatment of monosyllables is that it renders the alignment of the final weak position (6W) meaningless, as this position could only be stressed if filled by a monosyllable, and monosyllables are not counted here. Therefore, 6W is vacuously 100% aligned by the present metric, and excluded from the Figure. In reality, 6W is strictly aligned: Virgil fills it with a monosyllable only 1.4% of the time, and most, perhaps all, of those monosyllables are unstressed (e.g. 56% of them are *est*).

Though strong and weak positions are separated in Figure 2, their alignment can be seen to follow nearly identical trajectories. In particular, alignment is middling at the opening, falling to a minimum in the second and third feet. It then rapidly ascends, reaching virtual categoricity in the cadence. It thus appears that stress is indeed metrically regulated, particularly given that the end of the line is crosslinguistically the locus of greatest strictness (Hayes 1983:373, Dell and Halle 2009, McPherson and Ryan 2017).

Nevertheless, the argument for stress sensitivity only goes through if it can be shown that the distribution in Figure 2 is the result of active preferences on the part of the poet, as opposed to being merely an automatic reflex of how stress is distributed in Latin words chosen to fit the template quantitatively. To this end, others (e.g. Sturtevant 1923a:54, 1923b:57, Allen 1973:337) have argued that the avoidance of hexameter-final monosyllables, which is without parallel in prose, can be explained by stress. If the final weak position were filled by a monosyllable, it would potentially receive stress itself, and the immediately preceding strong position would lack stress, unless it too were filled by a monosyllable. Similarly, words of the shape ‒‒× are arguably avoided as hexameter endings because the immediately preceding fifth strong position would lack stress, unless filled by a stressed monosyllable. In fact, Virgil almost always (∼97% of the time) ends the line with a word of the shape ‒× or ◡‒× (where × is a syllable of any weight), arguably because these are precisely the two shapes that guarantee a fully aligned cadence. In prose, by contrast, only 20% of sentences end with these two word shapes, judging by a sample of 2,507 sentences by Caesar and Nepos. Even if we confine the prose sample to sentence-final words that would fit the end of the hexameter quantitatively, only 39% are ‒× or ◡‒×. Thus, Virgil's strong preference for these shapes is not motivated by the template in (6), but is simply explicable in terms of stress.

To demonstrate stress sensitivity more generally, one can compute an expected distribution of stress under the null hypothesis that the meter ignores stress. In this case, three baselines were estimated, as shown in Figure 3. Unlike Figure 2, strong and weak positions are now collapsed into a single connected line for each corpus. The first baseline, entitled 'Virgil shuffle,' constructs hexameter lines by concatenating words chosen at random from the entire Virgil corpus (cf. the 'Rigged Veda' of Gunkel and Ryan 2011:66; also Janson 1975 for a different permutation method for Latin). Constructed lines were retained only if they matched the hexameter template (after applying normal sandhi) and had a word break in the

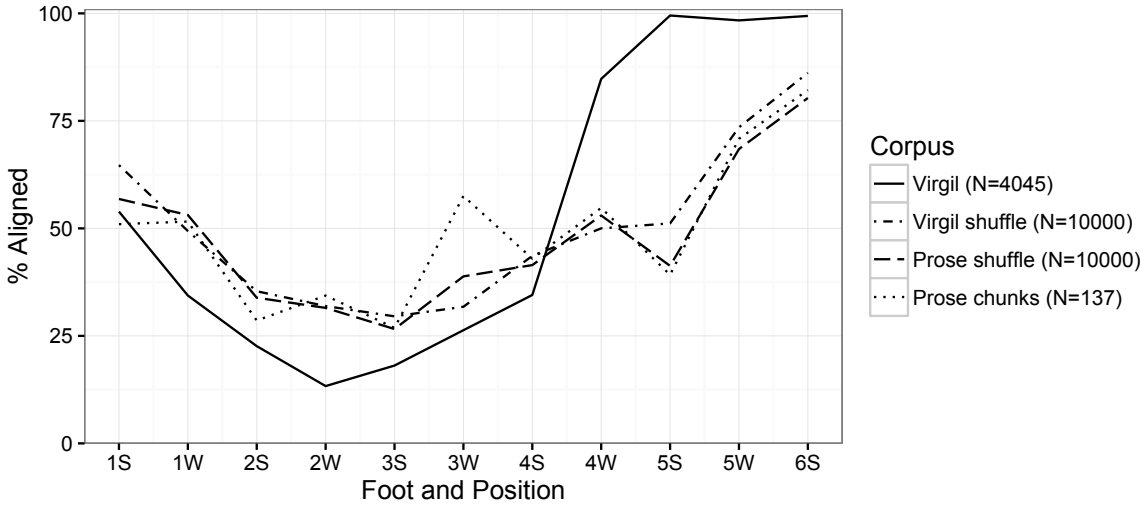


Figure 3: Alignment in the Latin hexameter, comparing real lines by Virgil (solid line) to three baselines of expectation.

third foot to serve as caesura.[7] Ten thousand lines were constructed. The second constructor, 'Prose shuffle,' is identical to the previous one except that it draws words from prose, namely, the Caesar and Nepos corpus mentioned above. Finally, 'Prose chunks' comprises all strings of any number of contiguous whole words from prose that scan as hexameters (on using prose phrases as a baseline to gauge metrical regulation, see Tarlinskaja and Teterina 1974, Tarlinskaja 1976, Gasparov 1980, Devine and Stephens 1976, Biggs 1996, Hall 2006, Hayes and Moore-Cantwell 2011, Bross et al. 2014, and Blumenfeld 2015).[8] Only 137 such accidental hexameters are found in 55,751 words of prose. Because 'Prose chunks' are so few in number compared to the other methods, they exhibit greater variance in alignment. In particular, the bump at 3W for 'Prose chunks' might not be meaningful, given the small sample size.

From Figure 3, it is once again clear that the strictness of the cadence (and, to a lesser extent, 4W) cannot be attributed to chance. This is most obvious for 5S, which is 99.5% aligned in the real corpus, vs. 39–51% in the baselines. Second, the constructed and real corpora exhibit an almost identical convexity in the PRECADENCE (here referring to the full line to the exclusion of the cadence), suggesting that the opening downtrend in Virgil is likely due to chance (on its offset from the baselines, see below).

Beyond the cadence, 4W, immediately preceding the cadence, is strongly (85%) aligned. Nevertheless, the alignment of 4W can be shown to be an artifact of the alignment of the

[7]Caesura was freely allowed to occur after the third strong position (STRONG CAESURA) or the first light syllable of the third weak position (WEAK CAESURA). Because Virgil usually (∼85% of the time) uses strong caesurae, one might argue that a better constructor would favor strong caesurae. In practice, leaving caesura uncontrolled achieved this bias. In 'Virgil shuffle,' 92% of caesurae were strong; in 'Prose shuffle,' 94%.

[8]Since enjambment is common in Virgil (cf. Dunkel 1996, Higbie 1990), these sequences were permitted to cross sentence, though not paragraph, boundaries.

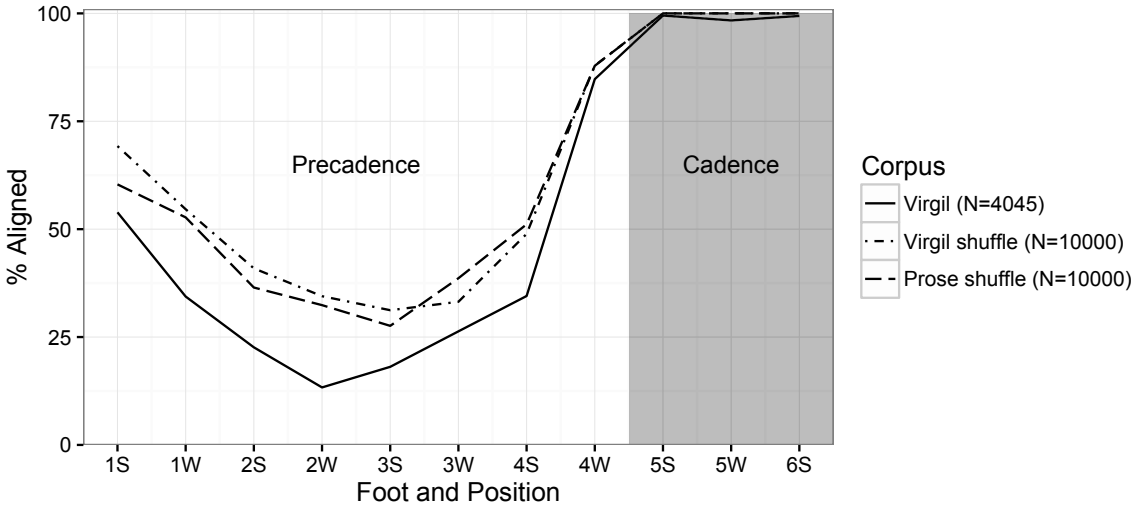


Figure 4: Alignment in the Latin hexameter, showing that alignment in 4W is an artifact of alignment in the cadence. Shuffles are now required to align in the cadence, which is grayed out.

cadence. Figure 4 shows alignment in the two shuffled corpora when the constructor is modified to require perfect alignment in the cadence. 'Prose chunks' are now omitted, as only five exhibit strictly aligned cadences. With this new requirement, 4W emerges as strongly aligned in the constructed corpora, even though it was not directly regulated. This is because when 5S is required to be stressed, 4W could be stressed only if filled by a stressed monosyllable (not counted here, as discussed) or pyrrhic disyllable, both uncommon.

To summarize thus far, the cadence virtually requires strict alignment of stress, while the high alignment of 4W can be attributed to chance, being a reflex of the strict cadence. Furthermore, the overall curvature of alignment in the precadence matches that of the baselines, indicating that it is likely also accidental. Nevertheless, one discrepancy remains: Prior to 4W, the real corpus is consistently about 10% worse aligned than the baselines. At first glance, this might be taken as suggestive that Virgil actively (if weakly) avoids alignment in that part of the line, as some scholars maintain (e.g. Ross 2007:146).[9]

However, there exists another possible explanation for the consistently lower rate of alignment in the precadence seen in Figures 3–4. The constructors above omitted consideration of a factor that plausibly influenced the poet, namely, making good use of the available lexicon (FIT in Hanson and Kiparsky 1996:294). Note that the cadence, requiring perfect alignment, accommodates only certain word shapes. For example, no word stressed on a light syllable (e.g. *cánō*) is permitted in the cadence, as such words necessarily induce non-alignment.

[9]Ross (*id.*) suggests that the preponderance of strong caesurae in the Latin hexameter can be explained by the preference for nonalignment in that vicinity, which strong caesura favors. As footnote 7 above noted, however, this bias for strong caesurae emerged when caesura placement was left uncontrolled by the constructors, and at higher rates than in Virgil to boot. Virgil's tendency to use strong caesurae could therefore be motivated purely by the statistical distribution of word shapes in Latin.

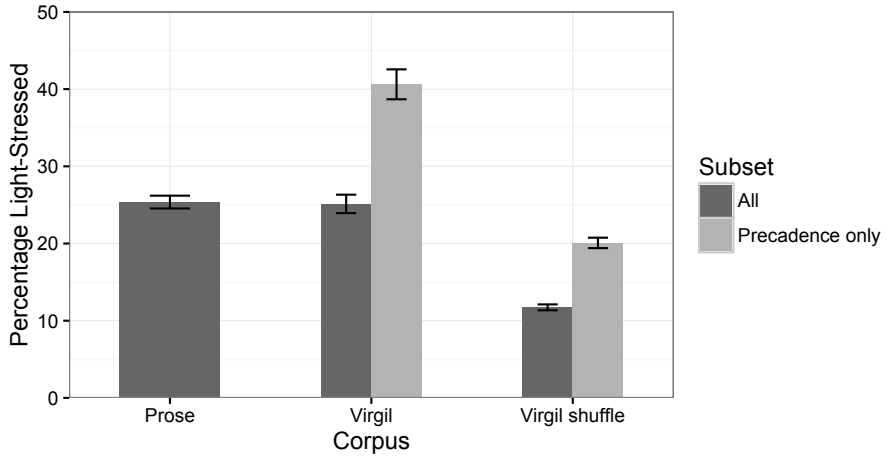


Figure 5: Proportion of words that are stressed on light as opposed to heavy syllables in three corpora. For the two poetry corpora, the overall rate is first shown (dark bar), followed by the rate in the precadence (light bar). The rate in cadences, being zero, is not shown.

Meanwhile, the vast majority of heavy-stressed words can be localized anywhere in the line, cadence or precadence.

In the aggregate, Virgil employs light-stressed words at the same rate as prose. As Figure 5 reveals, 25% of non-monosyllabic words in the *Aeneid* are light-stressed, approximately the same proportion as in prose (25%). In this sense, Virgil is making good use of light-stressed words. However, because light-stressed words cannot occupy the cadence, this situation entails that they must be overrepresented in the precadence, where 41% of words are light-stressed, almost double the prose rate. Thus, Virgil arguably overutilizes light-stressed words in the precadence not because he favors stress misalignment, but because he seeks to exploit the full range of Latin word shapes at approximately baseline (prose) rates, insofar as the meter permits.[10] In fact, he overutilizes light-stressed words in the precadence just enough so that the aggregate rate of usage in poetry matches that of prose, a fact that must be written off to coincidence by accounts proposing misalignment as an end in itself.

The constructors above failed to capture this effect because they had no incentive to achieve a good fit with the lexicon. For instance, only 12% of words in the 'Virgil shuffle' corpus were light-stressed, half the rate found in prose (Figure 5). Even though the constructor sampled randomly from Virgil, meaning that light-stressed words were initially sampled at Virgil's rate, candidate lines containing light-stressed words were less likely to survive scansion, resulting in their underrepresentation in the final shuffled corpus.

To conclude, this study corroborates the traditional view that the cadence (final two feet) of Virgil's hexameter requires not just quantity, but also stress, to align with the meter. The high alignment of the fourth weak position, immediately preceding the cadence, is demonstrated to be an artifact of the regulation of the cadence. The remainder of the line

[10]Some word shapes, such as any containing a non-final ⏑⏑⏑ or ‒⏑‒ sequence, are unmetrifiable as such. This does not affect the argument: Virgil seeks a good fit to the lexicon to the extent that the meter permits.

either ignores or slightly avoids stress alignment. This section has argued for the former, on the grounds that the observed degree of misalignment is precisely that required to achieve an aggregate distribution fully representative of the (metrifiable) lexicon. Moreover, the present analysis obviates what would otherwise be a counter-universal in metrics, namely, a metrical system in which demonstrably strong positions actively select for weak (i.e. unstressed) syllables. With these results, in short, we can tentatively conclude that stress is regulated strictly in the cadence but ignored elsewhere, at least for the purposes of metrical mapping.

1.2 The Latin hexameter: analysis

Stress alignment can be enforced by the constraint STRONG⇔STRESS, as in (7). Because of the bidirectional implication, this constraint penalizes both (a) a strong position that lacks stress and (b) stress in a weak position. In other words, it subsumes two constraints that in the formalism of Hanson and Kiparsky (1996) would be S⇒P (where S is 'strong' and P is 'prominent') and W⇒¬P, the latter equivalent to STRESS⇒STRONG.

(7) STRONG⇔STRESS$_{Cadence}$: In the cadence,
(a) a metrically strong position must dominate a stressed syllable, and
(b) a stressed syllable must be dominated by a metrically strong position.

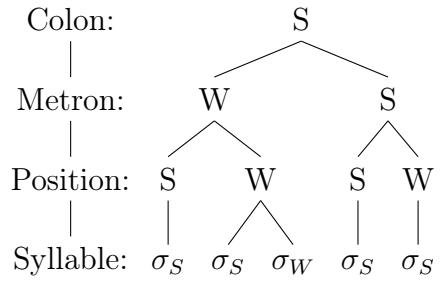
As discussed in §1.1, STRONG⇔STRESS is only active in the cadence, and must therefore be indexed to this domain. Two approaches to defining this domain would work equally well for present purposes. The first assumes that the cadence is reified in metrical structure as a constituent directly dominating the final two metrical feet. (Identifying the cadence as a constituent does not imply that the precadence is also a constituent.) The second approach takes the domain to be the final (or strong) colon, if such a constituent exists (see e.g. Barnes 1986). The two domains potentially differ for lines such as (8-a), whose cadence is *-rántque per áurās*, splitting a word, but whose final colon would perhaps be *verrántque per áurās*. In either case, strict alignment is observed. The colon could only potentially violate alignment if it extended back to 4S, as perhaps in (8-b). However, such cases are uncommon (2.7% of lines), and could still be analyzed as having secondary stress in 4S.

(8) a. $|_1$*quíp.pe* *.fé*$|_2$*rant* *.rá.pi*$|_3$*dī* *.sḗ*$|_4$*cum* *.ver*$|_5$*ránt.que* *.pe*$|_6$*r áu.rās*
b. $|_1$*ad* *.póe*$|_2$*nam* *.púl*$|_3$*chrā* *.prō* $|_4$*lī.ber*$|_5$*tā́.te* *.vo*$|_6$*cā́.bit*

A metrical structure for the cadence (or strong colon) is given in (9). Every node is either metrically strong (S, head) or weak (W, non-head). With Halle (1970) and Prince (1989), the dactylic-spondaic metrical foot (METRON) is taken to be left-headed, with the weak branch comprising either two light syllables or a single heavy. The final metron alone, however, cannot be a dactyl (_⏑⏑). On one analysis (Prince 1989:57), this is because final light syllables undergo moraic catalexis, rendering them metrically heavy; _⏑_ would then violate FTBIN below. I assume that strength is right-oriented at and above the level of the metron to comport with natural prosody and final strictness (Piera 1980, Hayes 1988,

Golston and Riad 2000, Hayes et al. 2012, Blumenfeld 2015, Kiparsky to appear).

(9)



Given this structure, constraints (10) through (12) implement quantity in the cadence. First, foot binarity (FtBin) — 'foot' here in the sense of moraic trochee, not metron — requires every position to be bimoraic, that is, either a heavy syllable or pair of lights (Prince 1989, Prince and Smolensky 1993). Second, (11) requires a light syllable in final position to be parsed as heavy, which has the joint effects of allowing a single light to comprise that position and of ruling out a dactyl there, which would be parsed as ◡–, violating FtBin. Finally, Strong⇒$\sigma_{\mu\mu}$ requires that the strong position of a metron contain a bimoraic syllable, ruling out anapests (◡◡–) and tetrabrachs (◡◡◡◡) while allowing dactyls (–◡◡) and spondees (––).

(10) FtBin: A position is bimoraic.

(11) Catalexis(μ): A line-final syllable is metrically heavy.[11]

(12) Strong⇒$\sigma_{\mu\mu}$: A strong position dominates a heavy syllable.

One final constraint warrants discussion here. The constraints discussed so far permit a cadence of the form ´– – ´– ×, with a spondee in the fifth foot. But Virgil almost always (over 99% of the time in the present corpus) implements the fifth foot with a dactyl. Weak⇒$\sigma_{\mu\,Cadence}$ in (13) therefore requires a weak position in the cadence to contain a light syllable. Together with FtBin, this ensures a dactyl. This constraint does not affect the final position, provided that FtBin and Catalexis(μ) dominate it. Moreover, because Virgil does occasionally permit spondees in the fifth foot, this constraint must be weighted rather than strictly ranked (cf. Hayes et al. 2012; (24) in §2.1 below).

(13) Weak⇒$\sigma_{\mu\,Cadence}$: In the cadence, a weak position dominates a light syllable.

The two cadential constraints are illustrated in (14). Candidates (a–e), above the dashed line, are the five most frequent cadences in Virgil.[12] None violates either constraint (their differing frequencies presumably reflect lexical resources, and perhaps other constraints not treated here). The remaining candidates (f–i) violate one or both constraints, and are less frequent or unattested in Virgil. Counts from the 'Virgil shuffle' corpus (§1.1) are provided

[11] On this usage of catalexis of a mora to implement final indifference, see Hanson and Kiparsky (1996:319).

[12] The breve standing alone in candidate (c) indicates that a short-voweled monosyllable has undergone resyllabification, as in *ab ŏrīs*. Otherwise, a single light syllable cannot be a word.

to reinforce that (f–i) would be expected to be frequent if these constraints were inactive.

(14)

Cadence	Virgil N	Shuffle N	STRONG⇔STRESS *Cadence*	WEAK⇒σ_μ *Cadence*
a. ´⏑⏑ ´ –	1,782	373		
b. ´⏑ ⏑´ –	1,605	291		
c. ´⏑ ⏑ ´ –	267	18		
d. ´⏑⏑ ´⏑	122	120		
e. ´⏑ ⏑´⏑	105	13		
f. ´– ´–	21	1,630		*
g. – ⏑⏑´⏑	1	325	*	
h. – –´–	0	939	*	*
i. –´– –	0	279	**	*

1.3 Old Norse

The Old Norse *dróttkvætt*, the most widely attested skaldic meter, shares with the Latin hexameter some relevant features discussed in §1.1. Each *dróttkvætt* line comprises six positions, of which the final two compose the cadence (Sievers 1893, Kuhn 1983, Árnason 1991, Gade 1995). As in Latin, the cadence is trochaic in both stress and weight,[13] such that its first position must be stressed and heavy, while its second must be unstressed and light (though final indifference may somewhat obscure the treatment of final weight).[14] Because primary stress is typically word-initial (Russom 1998), the vast majority of lines end with heavy-initial disyllables, as in (15), though longer words with compound stress are also possible, e.g. (15-c). The acute in orthography indicates length, not stress.

(15)
a. $|_1$*ungr* $|_2$*stil*$|_3$*lir* $|_4$*sá* $|_5$*mil*$|_6$*li*
b. $|_1$*prý*$|_2$*ðir* $|_3$*fað*$|_4$*minn* $|_5$*frí*$|_6$*ða*
c. $|_1$*al*$|_2$*dyggr* $|_3$*se*$|_4$*lund*$|_5$*byg*$|_6$*gva*
d. $|_1$*bitu* $|_2$*fí*$|_3$*ku*$|_4$*la* $|_5$*fjǫt*$|_6$*rar*
e. $|_1$*tolf* $|_2$*hǫfum* $|_3$*grǫf* $|_4$*hjá* $|_5$*gjalf*$|_6$*ri*
f. $|_1$*Þróask* $|_2$*ek*$|_3$*ki* $|_4$*mér* $|_5$*rek*$|_6$*ka*

Each position usually accommodates a single syllable, as in (15) (a–c), but resolution allows a position to be filled by two syllables, of which the first is light, a typologically frequent license (Hanson 1991, Hanson and Kiparsky 1996:296ff; cf. (20) in §2.1). Resolution is most frequently encountered in the first (d) or second (e) position of the line, and never in the cadence. Because long vowels normally scan as light in hiatus (i.e. immediately preceding another vowel), they too can participate in resolution, as in (f) (cf. Gade 1995:29).

[13]The Latin metron is dactylo-trochaic, but I assume with Halle (1970 et seq.) that dactyls are SW and hence trochaic at the level of the metron.

[14]Final indifference refers to the near-universal by which quantity is ignored line-finally or prepausally in quantitative meters, as also seen in Latin in §1.2. The *dróttkvætt* shows a clear tendency for final position to be light $C_0\check{V}$ (or semi-light $C_0\check{V}C$), though more complex rimes are occasionally encountered. On weight gradience in Old Norse, see Ryan (2011).

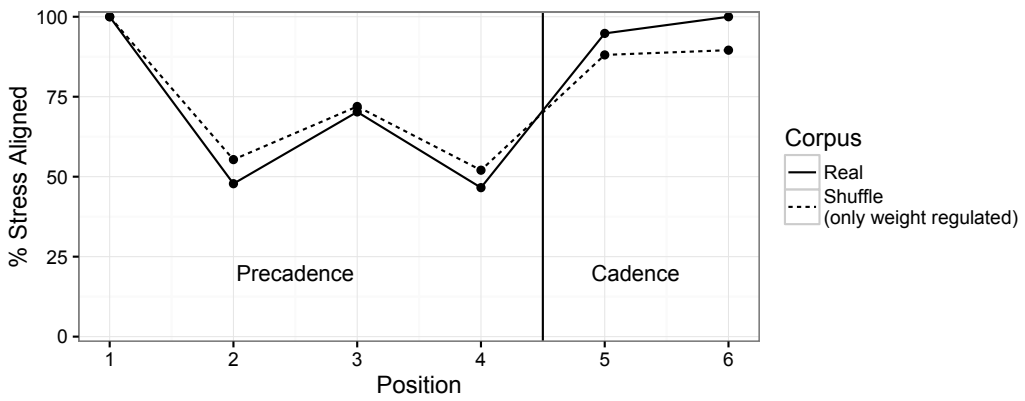


Figure 6: Percentage of the time that a position is aligned for stress across positions of the *dróttkvætt* vs. a 'shuffle' corpus in which only weight is regulated in the cadence.

As with Latin (§1.2), STRONG⇔STRESS$_{Cadence}$ is evidently active in Old Norse. In this meter, the cadence can be identified as the strong metrical foot, assuming, as before, that strength is right-oriented above the position (cf. Hayes et al. 2012:697). If so, the index 'Cadence' could be replaced by 'Foot$_S$.' If this constraint were inactive, we would expect to find more cadential monosyllables and polysyllables at the expense of disyllables. To be sure, line-final polysyllables do occur, as in (15-c), but arguably fewer than would be expected if stress were ignored. For example, Figure 6 compares the distribution of primary stress alignment in the real corpus (solid line) to that of a shuffled corpus (cf. §1.1) in which cadences were required to be heavy-light but stress was ignored.[15] The real corpus consists of 11,252 lines downloaded from the Skaldic Project (www.abdn.ac.uk/skaldic) that an automated parser identified as *dróttkvætt*. Stress is significantly (Fisher's exact test odds ratio (OR) = 4.7, $p < .0001$) better aligned in the real corpus. This model thus supports the insufficiency of weight-mapping alone.

Weight-mapping in the cadence can be treated comparably, with STRONG⇔HEAVY$_{Cadence}$. Once again, this constraint is needed independently of stress-mapping. If only stress were regulated, we would expect to find light-initial disyllables in the cadence as well as many more heavy-final disyllables. Figure 7 quantifies this expectation by testing a shuffled corpus in which only stress is regulated in the cadence. As expected, weight is significantly (OR = 10.4, $p < .0001$) better aligned in the real corpus.

The remainder of the line, whose metrical analysis is more subtle and controversial (cf. e.g. Árnason 1991, 1998, 2009, Gade 1995; footnote 15), is put aside here. It is possible that a fuller analysis would reveal that the meter has stress-modulated properties, like the meters analyzed in §2. At least for the *dróttkvætt* cadence, however, stress-mapping and weight-mapping can be treated as independent constraints, both separately justified, just as

[15]For present purposes, a V̆C rime is counted as light line-finally; see footnote 14. The precadence is assumed to have the structure SWSW, which is almost certainly an oversimplification (Árnason 1991, Gade 1995), but irrelevant here, as only the cadence is under scrutiny.

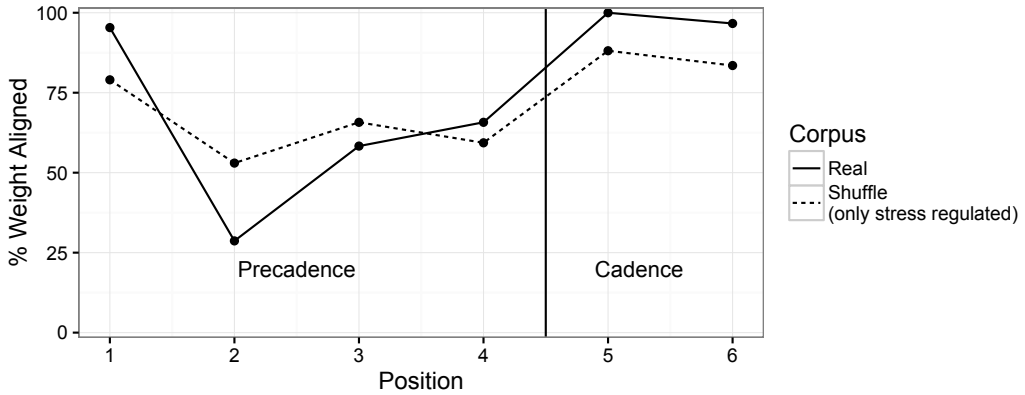


Figure 7: Percentage of the time that a position is aligned for weight across positions of the *dróttkvætt* vs. a 'shuffle' corpus in which only stress is regulated in the cadence.

they were for the Latin cadence.

2 Interactive stress- and weight-mapping

In Latin and Old Norse, the metrical treatment of stress and weight required separate sets of mapping constraints. This section treats accentual-quantitative meters in which stress and weight interact and must therefore be copredicates of the same constraint, along with meter. Such meters are termed STRESS-MODULATED, in the sense that weight-meter mapping is regulated more strictly for syllables with greater stress. Two genealogically unrelated cases are described and analyzed here, namely, Tamil (§2.1) and Kalevala Finnish (§2.2).

2.1 Tamil

Tamil exhibits a wide variety of quantitative meters (Niklas 1988, Zvelebil 1989, Rajam 1992), of which the popular *āciriyam* (*op. cit.*, Hart and Heifetz 1988, Parthasarathy 1992) is considered here, and more specifically, the subtype of *āciriyam* schematized in (16). This meter is one of the most frequent in the medieval Tamil epic, the *Rāmāyaṇa* of Kambar, the corpus employed here (Hart and Heifetz 1988; critical edition Kamban̲ 1956).

(16)

Foot 1		Foot 2		Foot 3		Foot 4	
S	W	S	W	S	W	S	W
{ – / ◡◡ }	×	–	◡ ×	–	◡ ×	–	◡ ×

Each line comprises four feet. Non-initial feet have the form [–][◡×], akin to the Latin dactyl, except that the final syllable is indifferent to quantity. The first foot is exceptionally trochaic [–][×] or, with resolution, [◡◡][×]. Each foot in turn comprises two positions, labeled S(trong) and W(eak) here, on analogy to the Latin (§1.1), though there is no basis

for this labeling in the tradition. In traditional terms, the first position (*acai*) of each [–][⏑×] metron is a *nēr-acai*, the second a *nirai-acai*, and the metron (*cīr*) as a whole a *viḷam-cīr*.

The first two quatrains of Kambar's epic are scanned in (17). A syllable is light iff it ends with a short vowel, including non-initial *ai* and *au*, noted here with breves. Final vowels usually scan as elided pre-vocalically, noted here by apostrophes. Resyllabification applies across words.

(17) 1a. $|_1$*u.la.kam* $|_2$*yā.văi.yum* $|_3$*tā.m* *u.ḷa*$|_4$*vāk.ka.lum*
1b. $|_1$*ni.lăi* *.pe*$|_2$*r̲ut.ta.lum* $|_3$*nīk.ka.lum* $|_4$*nīṅ.ka.lā*
1c. $|_1$*a.la.k'* *i*$|_2$*lā* *vi.lăi*$|_3$*yāṭ.ṭ'* *u.ṭăi*$|_4$*yā.r* *a.var*
1d. $|_1$*ta.lăi.va*$|_2$*r* *an̲.n̲a.vark*$|_3$*kē* *.ca.raṇ* $|_4$*nāṅ.ka.lē*

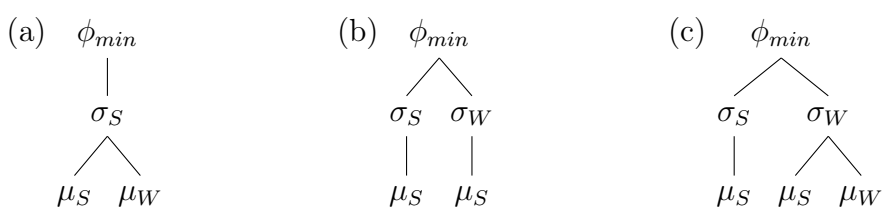
2a. $|_1$*cir̲.ku*$|_2$*ṇat.tar* *.te*$|_3$*ri.v'* *a.ru* $|_4$*nal* *.ni.lăi*
2b. $|_1$*er̲.k'* *u*$|_2$*ṇart.t'* *a.ri*$|_3$*t'* *eṇ.ṇi.ya* $|_4$*mūn̲.r̲i.n̲uḷ*
2c. $|_1$*mur̲* *.ku*$|_2$*ṇat.ta.va*$|_3$*rē* *.mu.ta*$|_4$*lō.r* *a.var*
2d. $|_1$*nar̲.ku*$|_2$*ṇak* *.ka.ṭa*$|_3$*l* *ā.ṭu.tal* $|_4$*nan̲.r̲'* *a.rō*

For present purposes, the first foot, being irregular, is put aside. The quantitative structure of the final three feet can be implemented by constraints (18) and (19). The first requires a metrical position to be a minimal foot (ϕ_{min}), that is, a heavy syllable ($\sigma_{\mu\mu}$), a pair of lights ($\sigma_\mu\sigma_\mu$), or a resolved moraic trochee ($\sigma_\mu\sigma_{\mu\mu}$), as depicted in (20).[16] ϕ_{min} is left-headed, and its leftmost (or only) branch is therefore labeled σ_S. σ_S refers here to the leftmost syllable of a metrical position, regardless of whether or not that syllable bears stress. Constraints (18) and (19) therefore require a strong metrical position to be $\sigma_{S\mu\mu}$ (i.e. (20) (a)) and a weak metrical position to be $\sigma_{S\mu}\sigma_{W\mu(\mu)}$ (i.e. (20) (b) or (c)). A weak metrical position can contain a heavy syllable, but only in its weak branch, explaining the indifferent (×) positions as well as the impossibility of substituting – for ⏑⏑, as in Latin.

(18) Pos = ϕ_{min}: Each metrical position is a minimal foot.

(19) Strong ⇔ $\sigma_{S\mu\mu}$: A strong metrical position must contain a heavy σ_S, and a heavy σ_S must be in a strong metrical position.

(20)



Nevertheless, exceptions to (19) are fairly frequent. Line (2a) above, for instance, contains two exceptions, double underlined in (21). Previous work (e.g. Hart and Heifetz 1988, Ryan 2011) acknowledges this exceptionality, but fails to note that such exceptions are almost

[16] On this usage of ϕ_{min} in metrics, see Hanson and Kiparsky (1996:296ff). ϕ_{min} was also the position size requirement for Old Norse in §1.3, given the possibility of resolving – as ⏑×.

entirely confined to unstressed syllables. Stress was likely uniformly initial in Old/Middle Tamil, the conservative Dravidian pattern (e.g. Zvelebil 1970, Hart and Heifetz 1988, Krishnamurti 2003; cf. also Christdas 1988, Bosch 1991, Beckman 1998, Schiffman 1999, Keane 2003, 2006 on modern Tamil).[17]

(21) 2a. $|_1 ci\underline{r}.ku|_2 \underset{\cdot}{n}at.\underline{\underline{tar}}\ \ .te|_3 \underline{\underline{ri}}.v'\ \ a.ru\ \ |_4 nal\ \ .ni.lăi$

Before examining this effect of stress, however, it is important to be clear that the meter is not accentual in the traditional sense. That is, there is no explicit tendency for stress to coincide with strong positions or non-stress with weak positions, as there is in languages such as English, Latin, and Old Norse. Figure 8 depicts the distribution of stress in the Tamil corpus, specifically, the first 624 lines of Kambar's epic in meter (16). In this corpus, stress is aligned (i.e. stressed in S or unstressed in W) at consistently ∼65% across positions. In the corpus as a whole, 67% of stressed syllables are heavy. Thus, the distribution is exactly what one would expect if quantity is regulated, but stress is ignored. To reinforce the argument, a 'Shuffle' corpus was constructed by concatenating words drawn at random from the real corpus (as in §1.1), keeping only lines that scanned as wellformed according to template (16), and ignoring stress. The distribution of stress in this shuffled corpus almost exactly matches that of the real corpus, supporting its non-regulation.

Although the meter does not regulate stress per se, it regulates weight more stringently for stressed than unstressed syllables, as shown by Figures 9 and 10. The effect of stress is most salient in strong positions: In this corpus, no stressed syllable is light in a strong position, but 14% of unstressed syllables in strong positions are light (Fisher's exact test OR $= 0$, $p < .0001$). In weak positions, stressed syllables are heavy 5% of the time, vs. 13% for unstressed syllables (OR $= 0.49$, $p < .0001$). Figure 9 shows the difference between stressed and unstressed syllables across positions of the line. It includes baseline rates (in the shaded region) based on a shuffled corpus controlling only for syllable count. Figure 10 shows the aggregate rate of heaviness in strong vs. weak positions as a function of stress.

The basic weight-mapping constraint for Tamil was defined above as STRONG⇔ $\sigma_{S\mu\mu}$. This analysis is now refined to accommodate the stress effect. Both stressed and unstressed syllables are regulated for weight, as the baselines in Figure 9 make clear; they differ only in their degree of regulation. Thus, STRONG⇔ $\sigma_{S\mu\mu}$ can be retained as a generic weight-mapping constraint that applies to all σ_S (i.e. metrical position-initial) syllables. Because there is no significant difference between strong and weak positions in the alignment of

[17] Malayalam, another descendant of Old Tamil, has been described as stressing the initial syllable unless the initial has a short vowel and the peninitial has a long vowel, in which case stress shifts to the peninitial (Mohanan 1989), and variants of this rule can be found elsewhere in Dravidian (Christdas 1996, Gordon 2004, Kolachina 2016). If this were Kambar's system, it would not qualitatively alter any of the conclusions here. Figure 10, when recomputed with Mohanan's stress, was almost imperceptibly affected. For one thing, the configuration for possible peninitial stress is very infrequent in Kambar. In the two stanzas quoted in (17), for instance, not a single word would qualify. Other close relatives of Tamil, such as Toda, are said to exhibit uniformly initial stress (Emeneau 1984).

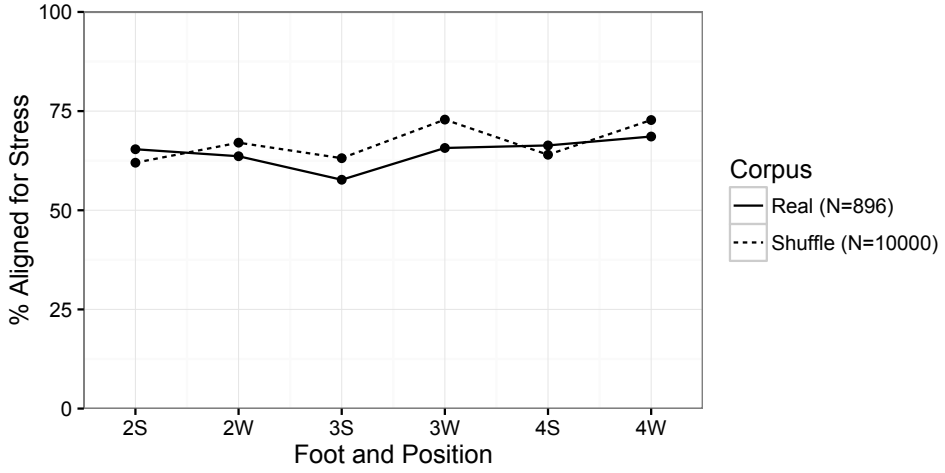


Figure 8: Percentage of stress alignment across the Tamil line, divided into feet (2 to 4) and position (S and W, excluding ×). Both the real distribution and a baseline of comparison are shown.

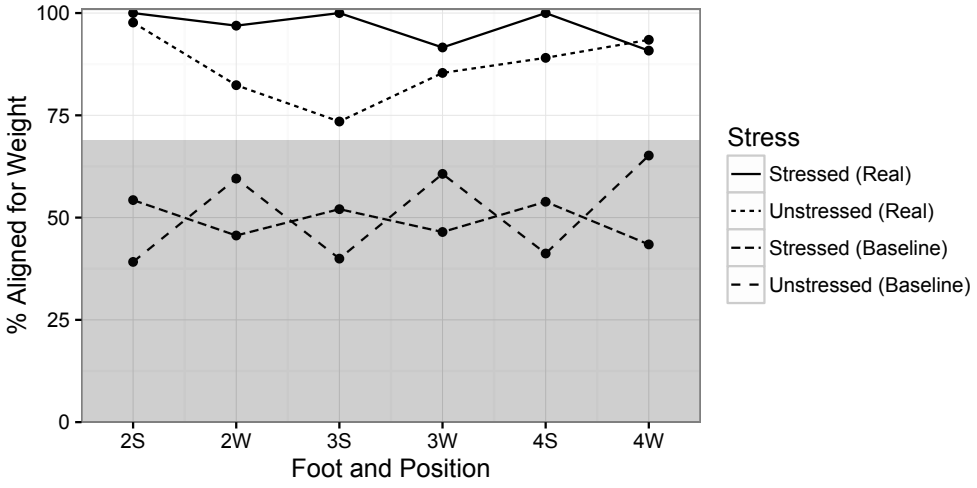


Figure 9: Weight alignment across the Tamil line as a function of stress level. The upper two lines are the real corpus; the bottom two (with gray background) are constructed baselines based on shuffles.

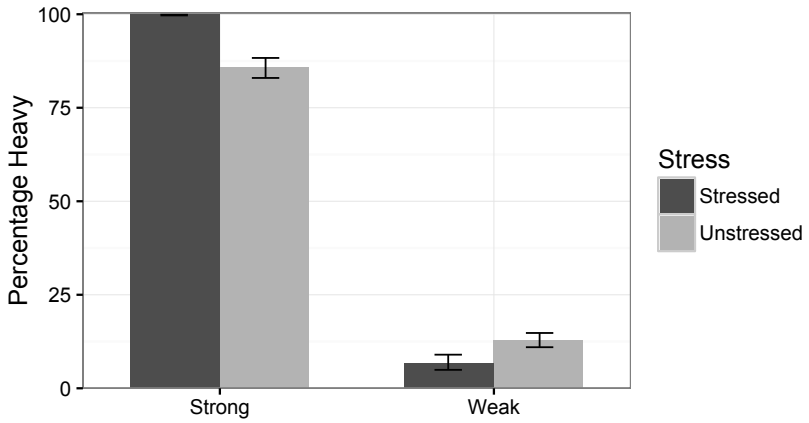


Figure 10: Weight is nearly categorically regulated for stressed syllables (dark bars), but less rigidly so for unstressed syllables (light bars).

unstressed syllables (14% misaligned in S vs. 13% misaligned in W), STRONG$\Leftrightarrow$ $\sigma_{S\mu\mu}$ can remain bidirectional, equally penalizing a heavy in W and a light in S. The constraint needs to be weighted, however, in order to account for the fact that weight-mapping in unstressed syllables is only a tendency.

Stress-modulated weight-mapping can be implemented by adding a stress condition to the weight-mapping constraint, as in (22) and (23). Because stress-modulation is more severe for strong positions, separate constraints are invoked for strong and weak positions. Constraint (23) specifies σ_S in order to ensure that syllables in the right branches of weak positions are unregulated.

(22) STRESS$\Rightarrow$(STRONG$\Rightarrow$HEAVY): If a syllable is stressed and in a metrically strong position, it must be heavy.

(23) STRESS$\Rightarrow\sigma_S\Rightarrow$(HEAVY$\Rightarrow$STRONG): If a syllable is stressed, σ_S (i.e. leftmost in its metrical position), and heavy, it must occupy a metrically strong position.

A weighted-constraints framework permits the modeling of both hard and soft constraints (for justification of such an approach to metrics, see especially Hayes et al. 2012; also Hayes and Moore-Cantwell 2011, Ryan 2011, McPherson and Ryan 2017). The most popular such framework for metrics has been maximum entropy Harmonic Grammar (MAXENT HG; *op. cit.*, Hayes and Wilson 2008 for a general introduction). Constraints are assigned numerical weights corresponding to their strictness. Each candidate line receives a penalty score that is the sum of its weighted violations, which can then be translated into a probability. Learning software by Wilson and George (2008) was used to train the weights of the three applicable mapping constraints on the Tamil corpus. Tableau (24) gives these weights and the penalties of four lines, two attested and two constructions (as indicated by †).

(24)

	Penalty	STRESS⇒(STRONG⇒HEAVY) $w = 11.9$	STRESS⇒σ_S⇒(HEAVY⇒STRONG) $w = 0.4$	STRONG⇔ $\sigma_{S\mu\mu}$ $w = 0.2$
a. $\|_1 u.la.kam \;\; \|_2 yā.vă i.yum \;\; \|_3 tā.m \;\; u.\underline{l}a\|_4 vāk.ka.lum$	0.0			
b. $\|_1 c\underline{i}r.ku\|_2 \underline{n}at.\underline{\underline{tar}} \;\; .te\|_3 \underline{\underline{ri}}.v' \;\; a.ru \;\; \|_4 nal \;\; .ni.lă i$	0.4			**
c. $^{\dagger}\|_1 mā.ti\|_2 ram \;\; .\underline{\underline{min}}.\underline{n}u\|_3 m \;\; a\underline{n}.\underline{r}' \;\; u.tă it\|_4 \underline{\underline{tu}} \;\; .\underline{\underline{mar}}.\underline{r}u$	1.4		**	***
d. $^{\dagger}\|_1 pal.lā\|_2 \underline{\underline{l}} \;\; \underline{\underline{i}}.ra.v' \;\; e\|_3 \underline{\underline{na}}.t' \;\; \underline{\underline{en}}.\underline{r}u \;\; \|_4 \underline{\underline{ti}}.\underline{n}a.vu$	25.0	**	*	****

2.2 Kalevala Finnish

Another example of a stress-modulated quantitative meter is provided by the Kalevala, a Karelian/Finnish epic of 22,795 lines, compiled and edited by Lönnrot (1849). The meter is trochaic tetrameter, as in (25). Each position normally accommodates one syllable, such that lines are octosyllabic. This count can be increased by resolution, particularly in the first foot. Moreover, the surface form of the line might have fewer than eight syllables due to the application of low-level phonological rules such as contraction and apocope, which Kiparsky (1968) analyzes as applying subsequent to metrification. Aside from the meter per se, lines normally exhibit alliteration and an avoidance of final monosyllables, the latter likely related to a more general tendency for longer words to go later in the line (Sadeniemi 1951, Kiparsky 1968, Kaukonen 1979, Leino 1986, 1994).

(25)

Foot 1		Foot 2		Foot 3		Foot 4	
S	W	S	W	S	W	S	W
–	◡	–	◡	–	◡	–	◡

Like Tamil, the meter is not accentual in the traditional sense. Primary stressed syllables, which are uniformly word-initial, are neither preferred in strong positions nor avoided in weak ones. As Figure 11 confirms, stress-meter alignment is middling throughout the line (except 4W), and never markedly higher than the baselines. 4W is highly aligned across all of the corpora because line-final monosyllables are infrequent. 4S is worse aligned than the baselines because the real corpus shows a stronger tendency for longer words to be localized finally, pushing back word-initial stress to earlier positions. But this 'end-weight' tendency is unrelated to stress-meter alignment; as the figure shows, it has the opposite effect.

The Finnish corpora were derived as follows. The Kalevala corpus comprises 22,795 octosyllabic lines extracted from an online edition of the text. Duplicate lines were removed, as was any line exhibiting possible application of Kiparsky's (1968) post-metrification rules of contraction, apocope, vowel lengthening, or gemination. Lines exhibiting possible application of any of these rules were easier to put aside than to correct (see Ryan 2011:424f). These various exclusions reduced the size of the corpus by 23%, to 17,486 lines. The 'Shuffle' corpus is a randomly permuted version of the real corpus, as in previous sections, with the same scansional criteria as for the real corpus. 'Prose chunks' comprise all octosyllabic phrases in

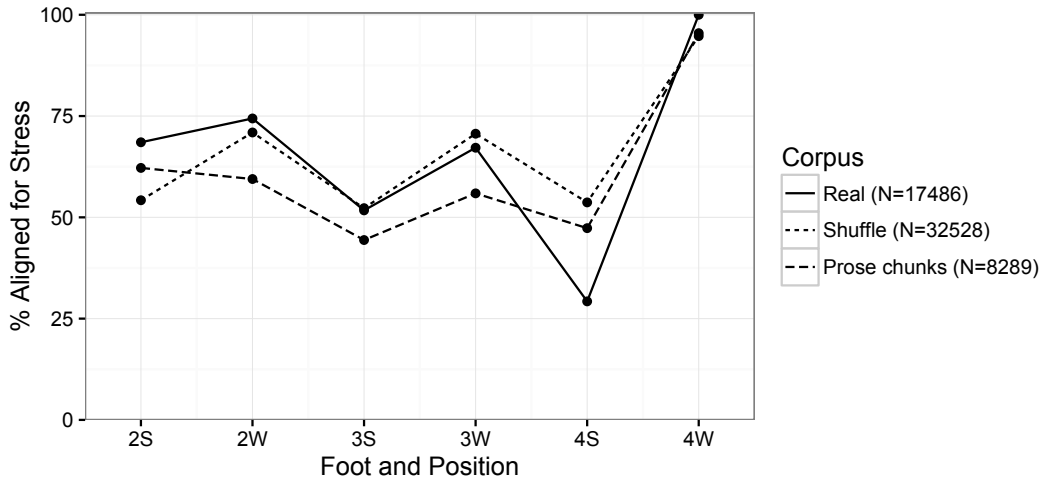


Figure 11: Stress alignment in the Kalevala. In strong positions, alignment is the percentage of syllables that is stressed; in weak positions, it is the percentage that is unstressed.

the Finnish Bible translation, *Vuoden 1776 Raamattu*. A phrase was operationalized as a sequence of one or more whole words standing between punctuation and summing to exactly eight syllables. 8,289 such phrases were extracted.

Weight-mapping in the Kalevala is stress-modulated. As traditionally described (Sadeniemi 1951, Kiparsky 1968), primary stressed syllables must be light (i.e. short-vowel-final) in W and heavy in S. Other syllables are said to be unregulated, as are subminimal clitics such as *ja* 'and,' presumably lacking stress. This mapping rule operates strongly only in the final three feet of the line. The first foot is virtually free; 35% of stressed syllables in it violate the rule. Exceptions are also encountered in the remainder of the line, but much less frequently (1.2% of stressed syllables in the second foot; 0.3% in the third; 0% in the fourth). Thus, oversimplifying only slightly, one can consider the first foot to be free and the latter feet to be strict. As such, the first foot is excluded from the present analysis.

Four illustrative lines are scanned in (26). Exceptions to the meter are double underlined. Unstressed syllables whose weight would conflict with the meter had they been stressed are single underlined.[18]

(26) a. $|_1$*ár.vo*$|_2$*an* *.á*$|_3$*jan* *.pá*$|_4$*rem.man*
b. $|_1$*ká.lan*$|_2$*lui.nen* $|_3$*kán.te*$|_4$*loi.nen*
c. $|_1$*hé.rai*$|_2$*se.na* $|_3$*hér.het*$|_4$*tä.vi*
d. $|_1$*éi* *.ól*$|_2$*lut* *.ó*$|_3$*so.a*$|_4$*ja.ta*

The aggregate effect of stress modulation in the final three feet is shown in Figure 12. As with Latin in §1.1, to avoid concerns about whether monosyllables — usually function words — are stressed or not, monosyllables are ignored, counted as neither stressed nor unstressed.

[18]Line-final position is taken to be metrically weak, though it might just as well be considered indifferent, and thus immune to exceptions. The question is moot, given that stressed syllables do not occur line-finally.

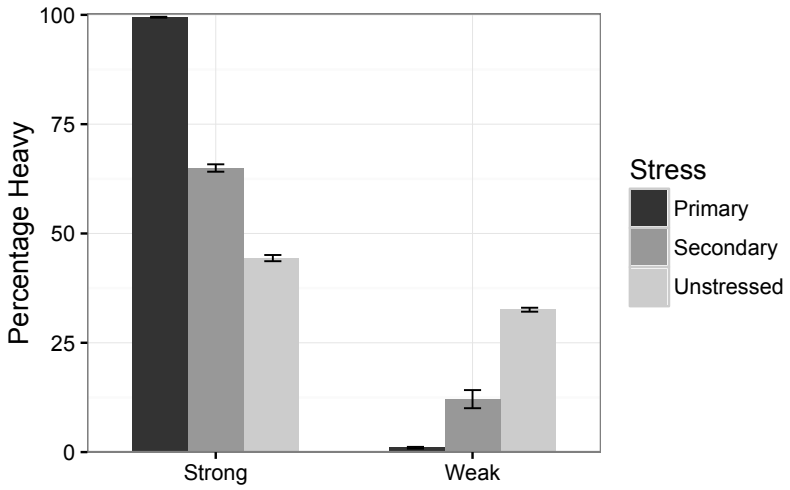


Figure 12: Rate of heaviness in strong vs. weak positions as a function of stress level. The first foot is excluded, as are monosyllables.

Primary stressed syllables are nearly categorically regulated for weight, being heavy 99.5% of the time in S and 1.0% of the time in W. This much is covered by the previous analyses, and can be implemented by the stress-modulated mapping constraint in (27), which has the same effect as the parameter settings in Hanson and Kiparsky (1996:308).

(27) MainStress⇒(Strong⇔Heavy): If a syllable is primary stressed and assigned to a metrically strong position, it must be heavy; if primary stressed and heavy, it must be assigned to a metrically strong position.

Figure 12 also raises the possibility that weight-mapping occurs at above-chance levels for syllables lacking primary stress. This finding, if substantiated, would comport with Tamil (§2.1), in which weight-mapping was nearly categorical for stressed syllables and weaker, but not ignored, for unstressed syllables. We can now also distinguish between secondary and no stress. Secondary stress was assigned to every other non-final syllable following primary stress, unless it would land on a light followed by a non-final heavy, in which case two syllables were skipped (e.g. *táittajàta*, *kúmottavàisen*; Hanson and Kiparsky 1996:301, Anttila 2010). As before, stress conditions are expressed in a stringency relation (cf. Prince 1999, de Lacy 2004). In §2.1, the conditions were 'stressed' and 'all,' the former a subset of the latter. Given three stress levels, the nested conditions are (1) primary, (2) primary and secondary, and (3) all, as reflected in constraints (28) (repeated from (27)), (29), and (30), respectively. In these descriptions, 'strong' should be taken as shorthand for 'assigned to a metrically strong position.'

(28) MainStress⇒(Strong⇔Heavy): If a syllable is primary stressed and strong, it must be heavy; if primary stressed and heavy, it must be strong.

(29) STRESS⇒(STRONG⇔HEAVY): If a syllable is stressed and strong, it must be heavy; if stressed and heavy, it must be strong.

(30) STRONG⇔HEAVY: If a syllable is strong, it must be heavy; if heavy, it must be strong.

The lines of the Kalevala were annotated for their violations of these three constraints and fed to the maxent HG learning program used in §2.1. Their resulting weights were 2.82, 1.16, and 0.32, respectively, jibing impressionistically with the progressively dwindling contrasts in Figure 12. Constraints (29) and (30) were also subjected to likelihood-ratio tests (Hayes et al. 2012:712). Both times, the superset model including the constraint significantly outperformed the subset model excluding it ($p < .0001$), justifying the three-constraint model over any one- or two-constraint alternative.

Another means of testing whether non-primary-stressed syllables are regulated is to compare their real alignment to that of the baselines described above. Figure 13 shows aggregate alignment per stress level in each corpus, based on the critical portion of the line, that is, the third through seventh positions. As before, the first foot is excluded, as is the final position, which may be indifferent. Unsurprisingly, primary stress, the leftmost group of bars, is best aligned in the real corpus. But this is now seen also to be the case for secondary and no stress, as the middle and rightmost groups of bars reveal. For every stress level, the real corpus (leftmost bar) is significantly better aligned than the comparanda. The comparanda are also now given in 'strict' versions, in which primary stress was required to align. These versions were included to demonstrate that secondary and unstressed alignment are not merely automatic reflexes of primary stress alignment.

In sum, the Kalevala meter requires weight to align with the meter (heavy in S and light in W) nearly categorically for primary stressed syllables. A new finding here is that non-primary stressed syllables also tend significantly to align with the meter, albeit more flexibly, just as they did in Tamil (§2.1). In the Kalevala meter, stress-modulation is gradient, such that primary stressed syllables are most strictly regulated, followed by secondary stressed and unstressed syllables in turn. This scale was proposed here to be implemented by mapping constraints conditioned on stress levels in a stringency relationship.

3 Discussion

As established in §2, among possible three-way mappings of stress, weight, and meter, only stress-modulated quantitative meters (schematically, STRESS⇒(STRONG⇔HEAVY)) are known to be attested. This section considers other logically possible three-way mappings and possible causes for their absence from the typology.

Before turning to three-way maps, however, consider first the simpler case of a two-way map, say, between stress and weight. Both STRESS-TO-WEIGHT ('penalize a stressed light') and WEIGHT-TO-STRESS ('penalize an unstressed heavy') are conventionally recognized (e.g.

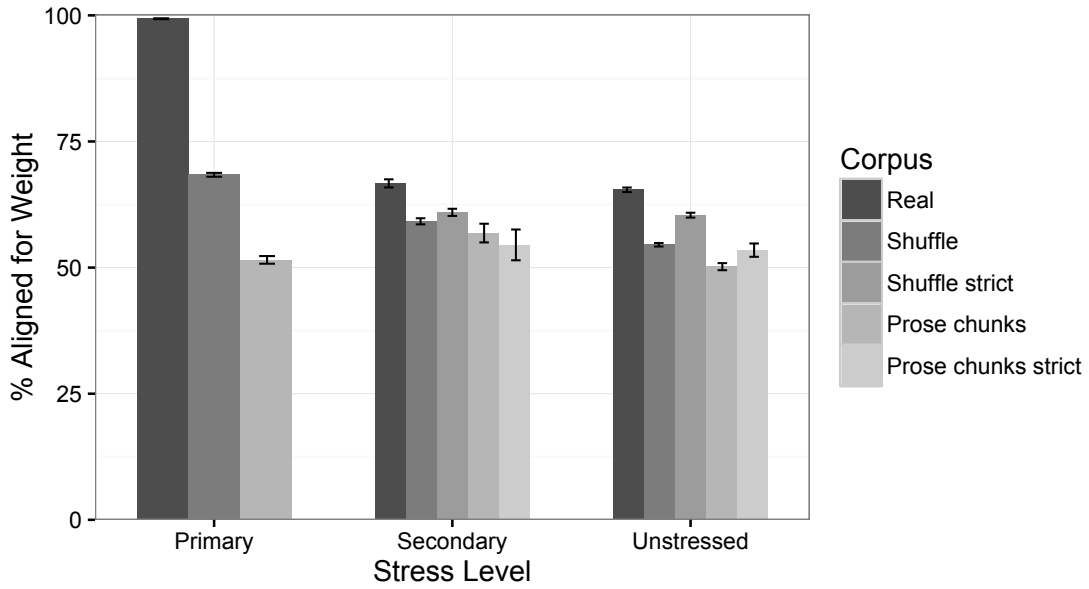


Figure 13: Weight alignment as a function of stress level in several corpora, including the real Kalevala (leftmost bar in each group) as well as four baselines of comparison (see text).

Prince 1990, Kager 1999, Smith 2002). These two constraints could also be formalized respectively as STRESS⇒HEAVY (or, equivalently, LIGHT⇒UNSTRESSED; as a rule, $p \Rightarrow q \equiv \neg q \Rightarrow \neg p$) and HEAVY⇒STRESS (or, equivalently, UNSTRESSED⇒LIGHT). Table (31) is a truth table (not a ranked tableau) showing the violations of all logically possible conditionals from stress ∈ {stressed, unstressed} to weight ∈ {heavy, light}, and vice versa. The columns are the four possible combinations of weight (_ for heavy and ◡ for light) and stress (superscript ´ for stressed and ˘ for unstressed).

(31)

			_´	_˘	◡´	◡˘
'Stress-to-Weight'	a.	STRESS⇒HEAVY			*	
'Weight-to-Stress'	b.	HEAVY⇒STRESS		*		
Redundant:	c.	LIGHT⇒UNSTRESSED			*	
	d.	UNSTRESSED⇒LIGHT		*		
Unnatural:	e.	STRESS⇒LIGHT	*			
	f.	LIGHT⇒STRESS				*
	g.	HEAVY⇒UNSTRESSED	*			
	h.	UNSTRESSED⇒HEAVY				*

Constraints (e–h) in (31) are unnatural, as each maps a strong element onto a weak element, resulting in a markedness reversal. By hypothesis — termed SCALAR ALIGNMENT in (32) — a legal mapping constraint can relate strong to strong and/or weak to weak, but not mix polarities. Although scales are treated as binary in this section, this principle extends straightforwardly to more complex scales if they are stringent, as they are throughout this article. In that case, 'strong element' can be read as 'class of elements that is contiguous with

the strong end of the scale.' For example, in Finnish, scalar alignment would be violated by both (more stringent) MainStress⇒Light and (less stringent) Stress⇒Light.[19]

(32) Scalar alignment: If a prominence-mapping constraint entails $p \Rightarrow q$, p and q must be of the same strength polarity, where e.g.

	Strong element	Weak element
Stress	Stressed	Unstressed
Weight	Heavy	Light
Meter	Strong	Weak

Table (33) shows the violation vectors of all 24 logically possible combinations of three terms in which each scale occurs once per constraint and polarities agree across terms. The horizontal axis now comprises all eight combinations of stress, weight, and metrical strength (S or W). Only unidirectional conditionals are shown. Biconditionals can be derived by combining constraints, in the sense of ranking them in the same place and pooling their violations (e.g. combining (a) and (c) yields Stress⇒(Strong⇔Heavy), which is violated whenever (a) or (c) is violated). Half of the constraints in groups 1–3 are redundant, since $p \Rightarrow (q \Rightarrow r)$ is equivalent to $q \Rightarrow (p \Rightarrow r)$.

[19]Scalar alignment does not rule out that opposite ends of scales might be required to coincide for reasons independent of prominence mapping. In Fijian, for instance, a long vowel shortens under primary stress (e.g. /siːβi/ → [ˈsiβi] 'to exceed'; Kager 1999:176). This trochaic shortening reflects a right-aligned moraic trochee, not a constraint of the type Stress⇒Light.

(33)

	ˋ/S	ˊ/S	ˋ/S	ˊ/S	ˋ/W	ˊ/W	ˋ/W	ˊ/W
Group 1 (attested)								
a. STRESS⇒(STRONG⇒HEAVY)			*					
b. STRONG⇒(STRESS⇒HEAVY)			*					
c. STRESS⇒(HEAVY⇒STRONG)					*			
d. HEAVY⇒(STRESS⇒STRONG)					*			
Group 2								
e. HEAVY⇒(STRONG⇒STRESS)		*						
f. STRONG⇒(HEAVY⇒STRESS)		*						
Group 3								
g. UNSTRESSED⇒(LIGHT⇒WEAK)				*				
h. LIGHT⇒(UNSTRESSED⇒WEAK)				*				
i. UNSTRESSED⇒(WEAK⇒LIGHT)						*		
j. WEAK⇒(UNSTRESSED⇒LIGHT)						*		
k. WEAK⇒(LIGHT⇒UNSTRESSED)							*	
l. LIGHT⇒(WEAK⇒UNSTRESSED)							*	
Group 4								
m. (HEAVY⇒STRONG)⇒STRESS		*		*				*
n. (STRONG⇒HEAVY)⇒STRESS		*				*		*
o. (HEAVY⇒STRESS)⇒STRONG					*		*	*
p. (STRESS⇒STRONG)⇒HEAVY			*	*				*
q. (STRONG⇒STRESS)⇒HEAVY			*				*	*
r. (STRESS⇒HEAVY)⇒STRONG					*	*		*
s. (LIGHT⇒WEAK)⇒UNSTRESSED	*				*		*	
t. (WEAK⇒LIGHT)⇒UNSTRESSED	*		*				*	
u. (LIGHT⇒UNSTRESSED)⇒WEAK	*	*		*				
v. (UNSTRESSED⇒WEAK)⇒LIGHT	*				*	*		
w. (WEAK⇒UNSTRESSED)⇒LIGHT	*	*				*		
x. (UNSTRESSED⇒LIGHT)⇒WEAK	*		*	*				

Of the constraints in (33), only group 1 is attested, though given the small sample size, one should be cautious about imputing impossibility to gaps. Nevertheless, some possible rationales for the absence of groups 2–4 are advanced in the following paragraphs. First, group 4 comprises constraints of the form $(p \Rightarrow q) \Rightarrow r$, in which a conditional serves as an antecedent. Each of these constraints implies a markedness reversal. For example, (m) penalizes ˋ/W but not ˊ/W. The latter is more marked, since it adds stress to a weak position. Group 4 can be ruled out by scalar alignment, as defined in (32). Although the terms ostensibly agree in polarity within each constraint, the way in which they are connected entails $p \Rightarrow q$ in which p and q conflict in polarity. A proof is given in (34), in which '≡' denotes logical equivalence and '⊢' denotes entailment.

(34)

	(HEAVY ⇒ STRONG) ⇒ STRESS	
≡	(¬HEAVY ∨ STRONG) ⇒ STRESS	$p \Rightarrow q \equiv \neg p \vee q$
≡	¬(¬HEAVY ∨ STRONG) ∨ STRESS	$p \Rightarrow q \equiv \neg p \vee q$
≡	(¬(¬HEAVY) ∧ ¬STRONG) ∨ STRESS	De Morgan's law
≡	(¬(¬HEAVY) ∨ STRESS) ∧ (¬STRONG ∨ STRESS)	distributive law
≡	(¬HEAVY ⇒ STRESS) ∧ (¬STRONG ∨ STRESS)	$\neg p \vee q \equiv p \Rightarrow q$
≡	(LIGHT ⇒ STRESS) ∧ (¬STRONG ∨ STRESS)	definition
⊢	LIGHT ⇒ STRESS	$p \wedge q \vdash p$ □

The remaining unattested groups — groups 2 and 3 — cannot be ruled out by scalar alignment. Group 3 contains constraints stated over weak terms. For example, (g) UNSTRESSED ⇒(LIGHT⇒WEAK) implements a meter in which strong positions must be heavy, but only unstressed syllables are evaluated. This is a type of stress-modulated quantitative meter, but evidently not a type that exists. In all known stress-modulated quantitative meters (as in §2), STRESS (or MAINSTRESS) serves as the antecedent. Group 3 can therefore tentatively be ruled out by the NO-WEAKNESS CONJECTURE in (35). Prominence-mapping constraints apparently need only to refer to strong elements. Indeed, none of the constraints posited in this article invokes a weak element; only STRESS, HEAVY, STRONG, and (in one case) σ_S are invoked. For a two-way conditional, this is arbitrary; for instance, LIGHT⇒WEAK is equivalent to STRONG⇒HEAVY, so one can simply translate between all-weak to all-strong formulations. Similarly, W⇒¬P in Hanson and Kiparsky (1996) ('a weak position must not be prominent') could also be expressed in terms of strong elements (e.g. STRESS⇒STRONG). But for a three-way mapping of the type $p \Rightarrow (q \Rightarrow r)$, such a translation is impossible. For example, UNSTRESSED⇒(LIGHT⇒WEAK) is crucially weak; it cannot be restated as $p \Rightarrow (q \Rightarrow r)$ in which p, q, and r are all strong elements.

(35) NO-WEAKNESS CONJECTURE: Prominence-mapping constraints must invoke only strong elements or classes.

Finally, consider group 2 in (33). This group permits the expression of two types of unattested modulations, namely, (b) and (c) in (36). The first, a WEIGHT-MODULATED ACCENTUAL METER, requires heavy syllables to be stressed in strong positions and unstressed in weak positions. The second, termed STRESS-MODULATED WEIGHT⇔STRESS, requires weight and stress to agree in strong positions.

(36)

	⏑̀/S	⏑̆/S	◡́/S	◡̆/S	⏑̀/W	⏑̆/W	◡́/W	◡̆/W
a. **Stress-modulated quantitative meter** (combines (33) a. and c.) STRESS⇒(STRONG⇔HEAVY)			*		*			
b. **Weight-modulated accentual meter** (combines (33) d. and e.) HEAVY⇒(STRESS⇔STRONG)		*			*			
c. **Strength-modulated weight⇔stress** (combines (33) b. and f.) STRONG⇒(STRESS⇔HEAVY)		*	*					

A few possible (not mutually exclusive) explanations for these gaps are considered here, though given the small size of the relevant typology (i.e. three cases of (36-a)), such a discussion is necessarily tentative. The first resides in the typology of privilege, where privilege refers to phonological elements that license other elements or processes by virtue of their salience or prominence. In surveys of privilege, stress is widely acknowledged to be such an antecedent, but weight is not (Beckman 2013). In this respect, stress-controlled weight-mapping may be more natural than weight-controlled stress-mapping, as stress is a more canonical realization of privilege/prominence than weight. Moreover, in the case of (c) STRONG⇒(STRESS⇔HEAVY), the embedded biconditional STRESS⇔HEAVY is not a possible meter, so it presumably cannot serve as the kernel of a modulated mapping on that ground.

A second potential justification for (36-a) as opposed to (b–c) concerns the origin and distribution of such meters. Hanson and Kiparsky (1996), following Sadeniemi (1949), note that quantity is only lexically distinctive in stressed (i.e. initial) syllables in (pre-)Kalevala Finnish; therefore, the stress antecedent in meter may reflect its role as a licensor in the general phonology. Something close to the same situation held in early Tamil. In many Dravidian languages, and possibly Proto-Dravidian, distinctive quantity is confined to initial position, as is stress (Barnes 2002:51ff). Middle Tamil represents a more complex situation, in which lexically distinctive quantity largely, though not entirely, correlates with initial position, which remained privileged in various ways (Beckman 1998). But under Sadeniemi's isomorphism hypothesis, this is exactly what one would expect for Tamil, given that it regulates initial syllables nearly strictly, and non-initial syllables intermediately. The degree to which this isomorphism holds typologically is left to future work. It is offered here merely as a plausible explanation for the selection of stress-modulated quantitative meters in languages such as Finnish and Tamil, but not, say, Arabic or Classical Latin.

In sum, this section suggested four possible restrictions on the typology of three-way prominence mappings. First, constraints must abide by scalar alignment, which guarantees that they do not impose any markedness reversals. Second, mapping constraints seem never to crucially invoke weak elements or classes. For example, UNSTRESSED is not known to serve as the antecedent of a stress-modulated quantitative meter. Thus, a no-weakness condition is hypothesized. Third, weight-modulated accentual meters may be unattested because such a modulation would violate hierarchies of privilege. Finally, a functional motivation for stress-modulated quantitative meters may reside in the prosodic isomorphism between metrics and the phonology of the language, in that both Finnish and Tamil are languages in which lexical distinctions in quantity were historically associated with accent.

4 Conclusion

While metrical prominence mapping is often exclusively accentual or quantitative, some meters are sensitive to both of these dimensions. Typologically, these hybrid accentual-

quantitative meters comprise two types, here termed independent mapping and interactive mapping. Independent mapping occurs when a meter requires both stress-mapping and weight-mapping constraints (schematically, STRONG⇔HEAVY and STRONG⇔STRESS), but no individual mapping constraint needs to invoke both stress and weight. It was illustrated here by Latin (Virgil's hexameter; §1.1–1.2) and Old Norse (the *dróttkvaett*; §1.3). In such a meter, all mapping constraints must answer to the same underlying meter; the situation is not one of simultaneous meters.

The second type of hybridity is interactive mapping, that is, meters in which one or more individual mapping constraints must refer simultaneously to weight, stress, and meter. Such meters are apparently universally stress-modulated quantitative meters (schematically, STRESS⇒(STRONG⇔HEAVY)), in which weight is regulated more strictly for syllables with greater stress. Furthermore, this modulation is typically (perhaps universally) gradient, such that the higher the stress level, the stricter the weight-mapping. But syllables without stress appear never to be wholly ignored. This was true for Middle Tamil (§2.1) and Kalevala Finnish (§2.2), both newly analyzed here, and also claimed for Serbo-Croatian by Jakobson (1952:418f; cf. Zec 2009). Stress-modulated quantitative meters constitute only a small subset of logically possible three-way prominence mappings. Several possible motivations for this typology, both formal and functional, were discussed in §3, including scalar alignment, the no-weakness conjecture, phonological privilege, and prosodic isomorphism between the meter and its associated language.

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