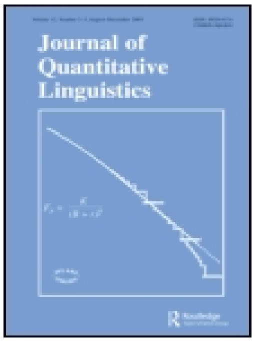

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Coevolution of Phonology and the Lexicon in Twelve Languages of West Africa *

Daniel Nettle
Merton College, Oxford, UK

ABSTRACT

Synergetic models of language structure predict that the length of a word will depend upon various parameters such as its frequency and the number of phonemes in the language. This prediction has been used to explain word length differences within languages, but less often to explain the differences *between* languages. Here I show that average word length across 12 West African languages is related to the size of the phonological inventory. This is an apparent example of the adaptation of language structure to the efficient communication of information. The hypothesised mechanism by which the relationship evolves are outlined.

WORD LENGTH: A SYSTEMS THEORETICAL MODEL

It has long been obvious that words have very different typical lengths in different languages, from the monosyllables of Chinese and other Asian languages, to the many-syllable roots of Hawaiian and the languages of Australia. Nonetheless, the word in its uninflected stem form is considered a basic, universal linguistic unit which is comparable across languages. The question thus arises of why words should be of such different composition in different languages.

Systems-theoretical linguistics treats a language as a dynamical, self-organising system whose structure is optimised to its function of communicating and representing information. The pressure exerted by function on structure is not uni-directional, however. Rather, languages evolve under several *competing motivations*, such as the minimisation of memory load and the minimisation of ambiguity, the minimisation of articulatory effort and the maximisation of acoustic distinctiveness. The interactions between these different pressures can be formalised into systems-theoretical models, and predictive statements about language structure produced (Köhler, 1986, 1987).

According to the synergetic models, the length of an individual word will be a function of the number of segments in the phonological inventory of the language, the word's frequency, the number of words in the lexicon, and the degree of redundancy which the language requires due to the noisy nature of the human speech channel. Where L is the length of a word, then:

$$L=a(\text{Segments}^b)(\text{Frequency}^c)(\text{Lexicon}^d)(\text{Redundancy}^e) \quad (1)$$

where a,b,c,d and e are constants.

This statement about the distribution of word length within a language can be modified to make predictions about typical word length *across* languages. If we take a sample of words of all different frequencies from a language, and average their length, then their mean λ will be distributed as:

$$\lambda = a\,(\text{Segments}^b)(\text{Lexicon}^d)(\text{Redundancy}^e) \quad (2)$$

We can reasonably assume that the redundancy parameter is constant across words and across

*Address correspondence to: Daniel Nettle, Merton College, Oxford OX1 4JD, Great Britain. Tel.: +44 1865 286474. Fax.: +44 1865 276361. E-mail: daniel.nettle@merton.ox.ac.uk

speech communities, given that the human speech mechanisms are the same everywhere. Furthermore, although there are differences in lexicon size between different languages, their effects will be negligible as long as all lexicons are large and d is small. We can therefore take (Lexicon^d) and (Redundancy^e) as constants when comparing across languages, giving:

$$\lambda = a\,(\text{Segments}^b) \qquad (3)$$

The prediction that there will be a relationship of the form given in (3) has already been tested and found to be correct for ten unrelated languages (Nettle, 1995). In this paper, I repeat the analysis for twelve West African languages, and then investigate the mechanisms which lead to the synergetic relationship.

TESTING THE PREDICTION

Methods

The data used to test prediction (3) were gathered as part of a wider investigation of the areal linguistics of West Africa (Nettle, 1996). The twelve languages were chosen for the quality of information available, and though they are all genetically or areally related in some way, the relationships are sufficiently uniform not to compromise statistical independence. To test the prediction, two data are needed for each language:

(i) *A phonological inventory*
This was obtained from published sources in all cases. The number of contrastive segments, henceforth S, was added up, using uniform criteria outlined in Nettle (1996). The figure desired is not simply the number of phonemes in the language by the traditional definition. Rather, it is the total number of possible contrasting segments which is of interest. This means for tone languages that each vowel/tone combination must be counted separately. Thus, a language with five vowels and three contrastive tones is deemed to have 15 possible contrasts on a vowel position. The measure S is the simple sum of vowel and consonant contrasts, and therefore takes no account of phonotactic rules operating in the language. It is thus a simplification, whose accuracy depends upon the similarity of phonotactics from language to language.

(ii) *An estimate of the average word length (λ)*
This was obtained by measuring the length in segments of randomly sampled lexical stems in a dictionary of the language, and taking their mean. It is important to stress that the unit under investigation here is the uninflected lexical stem. The cross-linguistic distribution of word token lengths in actual texts is heavily affected by the morphological typology of different languages, and so would require a much more complex model than that presented here.

The results of Nettle (1995) suggested that a sample of 50 word stems was sufficient to produce an estimate of λ. There is, however, a danger that the word length distribution will be confounded by the size of the dictionary used, since smaller dictionaries will contain more common words, which in turn tend to be shorter. An analysis in Nettle (1995), however, showed that the influence of dictionary size is negligible as long as all dictionaries contain more than 1000 entries.

RESULTS

The number of segments in the inventory of the language (S), and the average word length (λ) are shown for each language in Table 1, along with the general location of the language, the number of speakers, and the sources consulted.

There is indeed a negative power relationship between λ and S, as Figure 1 shows. Curve estimation using the SPSS computer package gives the equation:

$$\lambda = 10.18\ S^{-0.18} \qquad (4)$$
$$(r = 0.77,\ d.f. = 10,\ p < 0.001)$$

The prediction of the systems-theoretical model is thus met, and the finding of Nettle (1995) for ten unrelated languages replicated. If the two data sets are combined, the following overall equation is produced:

$$\lambda = 17.87\ S^{-0.31} \qquad (5)$$
$$(r = 0.82,\ d.f. = 20,\ p < 0.001)$$

Table 1. Inventory Size (S) and Average Word Length (λ) for the Twelve Languages, with General Location, Number of Speakers, and Source Consulted.

Language	Location	Sp*	S	λ	Phonology	Dictionary
Fula	Widespread	19404	33	6.42	Dunstan (1969)	Noye (1989)
Hausa	N. Nigeria	8000	35	5.68	Jaggar (1993); Dunstan (1969)	Kraft and Kirk-Greene (1973)
Tamasheq	Mainly Mali	7500	36	5.26	Mali (1987)	Mali (1986)
Songhai	Mali	675	42	4.96	Stappers (1964)	Ducroz (1978)
Bambara	Mali	1500	49	4.86	Bird et al. (1977)	Ebermann(1986)
Ngizim	N. Nigeria	59	52	5.32	Schuh (1981)	Schuh (1981)
Edo	S. Nigeria	1000	53	4.42	Kropp-Dakubu (1980)	Agheyisi (1986)
Igbo	S. Nigeria	2887	58	4.62	Dunstan (1969)	Williamson (1972)
Mende	Sierra Leone	940	71	4.7	Innes (1967)	Innes (1969)
Ewe	Ghana/Togo	3238	81	4.16	Nutinunya (1974)	Rongier (1988)
Vata	Ivory Coast	5	164	4.56	Vogler (1987)	Vogler (1987)
Vute	Cameroon	33	195	3.94	Guarisma (1978)	Guarisma (1978)

* Speakers, thousands.

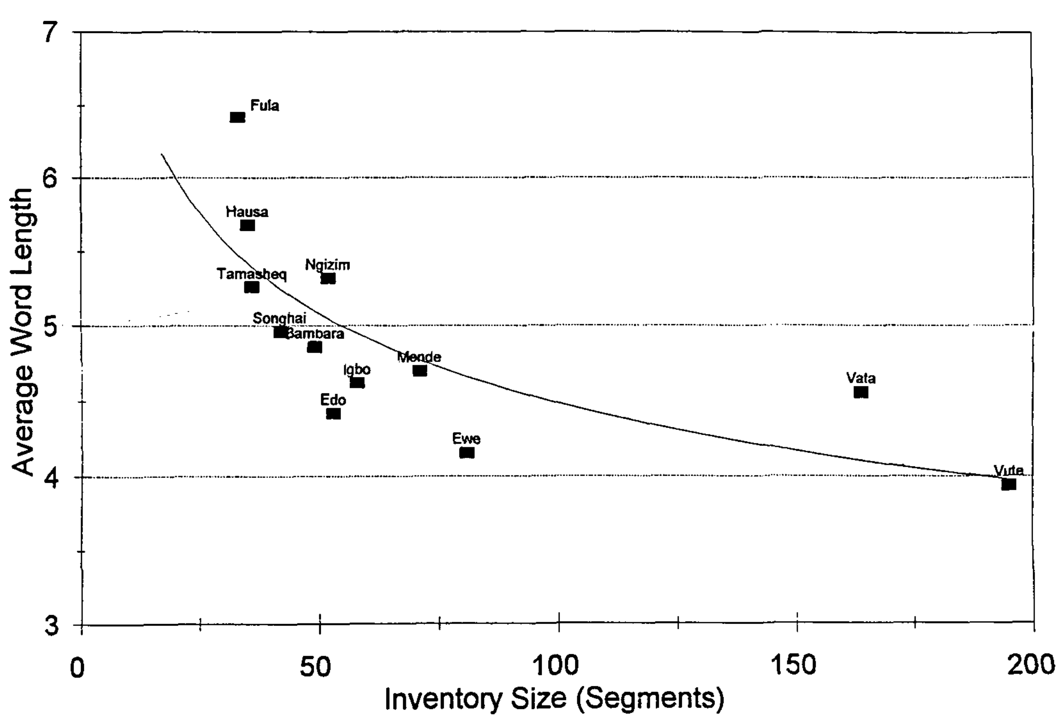

Fig. 1. Plot of the relationship between the number of segments (S) and the average word length (λ) for the twelve languages.

DISCUSSION: MECHANISMS OF LANGUAGE ADAPTATION

The observed relationship is a clear example of functional coevolution in language. Larger phonological inventories allow more economical coding of word-meanings, and the results show that languages with such inventories do optimise their codings accordingly. The findings are thus consistent with the view that language structure develops in such a way as to be adapted to efficient functioning.

Two questions arise from these results. First, we have not really explained the observed relationship until we have clarified how the adaptation of structure to function comes about. In this section, then, I look at the mechanisms governing word length and phonological inventory in the history of languages. Second, we have to explain why different languages find different equilibria between the two variables. This issue will also be discussed below.

Zipf (1949) was one of the first to discover adaptive relationships in language structure, such as that between the length of a word and its frequency. He described his results as the outcome of the operations of a master-craftsman, whose operations on the system of language have made it maximally convenient as a tool for communication. We should, however, be careful about how we interpret this metaphor. There is no guiding intelligence which is responsible for the global design of a language. Unlike craftsmen, the speakers of languages do not intend languages to change in one way or another. The evolution of the language is rather the unintentional by-product of simple patterns of speaker behaviour. To explain language adaptation, then, we must show how the actual performance of speakers, hearers and learners could, over the history of a language, lead to the emergence of adaptive patterns.

In linguistic performance, we observe a constant stream of minor variants on canonical word forms. In particular, words in fluent speech tend to be truncated (Lieberman, 1963) – final segments are shortened, omitted or not released. New learners of the language are then exposed to a range of tokens of each word, from the full form to variously reduced ones. Because of the least effort properties of motor learning, learners are always likely to select shorter form over longer ones where both are equally intelligible. Thus, over generations, word forms will be progressively reduced in length (Lüdtke, 1986).

Phonological segments colour those that precede them in the speech chain, a phenomenon known as coarticulation. Where final segments are reduced, hearers may use the coarticulated cues on earlier segments to identify the word. For example, word-final nasals are often not released, but lead to the phonetic nasalisation of the preceding vowel. If truncation of the nasal continues, the final nasal will disappear and learners will reanalyse the contrast as one between plain and nasalised vowels. Such a process has occurred in French, with forms such as *bon* [bɔ̃]. Thus two linked changes have occurred; a class of words has got shorter, and the number of phonological contrasts in the language has increased. Similar processes have often been observed in tone languages (Hombert, 1972; Matisoff, 1973). Contrasts in voicing on syllable-final consonants are gradually transferred to contrasts in pitch on the preceding vowel. The consonants the disappear, leaving shorter words and a straightforward tonal contrast signalling meaning distinctions.

In general, then, the processes of underarticulation and language acquisition, which are influenced by considerations of articulatory economy, lead to a gradual increase in the number of phonological contrasts in the inventory and a shortening of word forms. Clearly, counterbalancing processes must be at work, or all languages would end up with maximal inventories and monosyllabic roots.

The incorporation of further contrasts into a phonological inventory reduces the acoustic and perceptual distance between the segments. It is well attested in the history of languages that when segments become phonetically very similar, they may merge. This is presumably due to new learners failing to discriminate the (similar or even overlapping) tokens of the two segments. As the phonological inventory gets larger, the probability of discrimination failures and the consequent segment mergers increases.

Where segments merge, previously distinct classes of words become homophones. Speakers can tolerate a certain amount of homonymy, but often they compensate in some way. Phonological mergers are not reversible, since once the merger has occurred there is no trace of which word belonged to which class. However, speakers can make distinctions by lexical strategies. The French word *hui* ('today'), for example, seems to have lost distinctiveness at some point in its evolution from the Latin *hoc diem*. Speakers have then compensated by expanding its morphological frame, to give *aujourd'hui* (Lüdtke, 1986). Similar examples can be found from many languages. In Chinese, where a series of phonological mergers led to pairs of monosyllabic roots becoming homophones, half developed into unambiguous disyllabic compounds by reduplication.

The process of segmental merger has two effects, then. Directly, it reduces the size of the phonological inventory. Indirectly, it leads to longer words since speakers compensate for homophony by lexical expansion. The effects of learner/hearer discrimination failure therefore precisely counterbalance those of articulatory economy. The actual word length and phonological inventory which a language has will therefore be the result of the equilibrium point of these two historical forces. The curve shown in Figure 1 is the region of possible equilibria which languages may adopt.

This still leaves the question of why some languages find quite different balances from others along the curve. I have no clear answer to this question; it may reflect no more than chance historical events. On the other hand, there could be some systematic relationship between the relative strength of the two forces and the circumstances of language acquisition and use in speech communities.

Jakobson (1929) noted that dialects which come to be used over a large area tend to undergo phonological simplification. Andersen (1988) gives a plausible account of the mechanism by which this might occur. The geographical range of a speech variety gets larger because individuals have larger or more dispersed social networks. This means that there will be more dialectal heterogeneity in the speech they experience, as a consequence of their being exposed to social contacts from a wider area or social range. They will hear a large scatter of different phonetic realisations for any individual phonological segment.

As this scatter increases, the likelihood of discrimination failure, and hence of phonological merger, for any two adjacent segments increases. Mergers will thus take place throughout the system until all the remaining segments are far enough apart to be reliably distinguished despite the level of dialectal variation. We might thus predict that languages or dialects used over very large areas will evolve towards a system of relatively few, widely spaced segments. In short, the influence of discrimination failure is predicted to be greater in large or dispersed communities since the amount of variation hearers experience will generally be greater.

This principle has great explanatory potential in West Africa. In general, there is a latitudinal cline in the phonological complexity of the languages (Nettle, 1996). That is, as one moves from North to South, the size of the phonological inventory of the languages increases. The languages of the desert and arid savannahs in the North of the sub-region have small vowel and tone systems (or are not tonal at all in the case of the most widespread language, Fula). The communities speaking these languages are large, nomadic, and dispersed over vast areas. In contrast, the languages of some of the small, sedentary groups of horticulturalists living in the South of the region have very complex tone systems, giving them some of the largest phonological inventories in the world.

Within the twelve languages of the present paper, the largest inventories are found in the smallest communities, and vice versa. There is a significant rank correlation between S (the inventory size) and the number of speakers ($r = -0.69$, $n = 12$, $p < 0.05$).

The explanation in terms of social network size seems, then, promising for the West African case. However, there are other parts of the globe whose situation it fails to predict. The languages of Australia, New Guinea, and the Pacific have a general tendency towards small phonological inventories, yet the communities involved are typically small groups of horticulturalists or foragers where one might expect, *ex hypothesi*, the conditions to be right for large inventories to evolve. These are not strict counter-examples to the hypothesis; that would require a language which was very widespread and had a very large phonological inventory. The nearest instance to this is probably Thai (Nettle, 1995), but even Thai does not have the extreme phonological complexity of Vata or Vute from the present study, or of !Kung from Southern Africa, which is also spoken by a very small group.

In conclusions, the factors which favour the augmentation of the phonological inventory or its reduction in particular languages demand further attention. Nonetheless, the twelve languages of West Africa discussed in this paper give us useful insights into how and why the phonological inventory and the lexicon coevolve in human languages.

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