Sonority and Climate in a World Sample of Languages: Findings and Prospects

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In a world sample (N = 60), the indigenous languages of tropical and subtropical climates in contrast to the languages spoken in temperate and cold zones manifested high levels of sonority. High sonority in phonetic segments, as found for example in vowels (versus consonants), increases the carrying power of speech sounds and, hence, audibility at a distance. We assume that in the course of daily activities, the speakers in warm/hot climates (a) are often outdoors due to equable ambient temperatures, (b) thereby frequently transmit messages distally, and (c) transmit such messages relatively intelligibly due to the acoustic and functional advantages of high sonority. Our conceptual model is similar to that of population biology, where there are well-known correlations be-

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tween climate and somatic variables, and where it is assumed that communicative modalities and behaviors are selected or designed for success in specific habitats. We also take up possible alternative hypotheses and consider directions for future research.

Keywords: *linguistic anthropology; communicative efficiency; sonority; climate*

This article reports results of an ongoing inquiry into certain phonetic regularities among the languages of the world. The research program began with the informal observation that many indigenous languages in tropical and subtropical areas seemed to exhibit high-frequency usage of the simple consonant-vowel (*CV*) syllable (as in Hausa *maraki* "calf" and Toradja *tawani* "slave"), whereas many languages in temperate and cold areas apparently manifested both a lower CV usage and a stronger consonant-clustering tendency (as in Klamath *tchkash* "also" and Russian *vrazbrod* "scattered"). Subsequently, a systematic study established that these perceived linguistic variations by climatic area did in fact exist (data not shown here) (Munroe, Munroe, & Winters, 1996). An attempt was made in that article to account theoretically for this association, but continuing research has revealed further regularities and prompted new interpretations (Ember & Ember, 1999, 2000; Munroe, Fought, & Fought, 2000). Our current formulation suggests that the difference in the phonetic systems of hot/warm- and cold-area languages shows up more clearly when measured as mean *sonority*. That is, indigenous languages spoken in tropical and subtropical climates in contrast to languages of temperate and cold zones show a significantly higher value for mean sonority in lexical and text samples. Sonority here is understood as acoustic

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energy: More sonorous phonetic segments are those that, assuming equivalence of pitch, length, and stress, have higher acoustic intensity (and are thus perceptually more salient).

In this article, we demonstrate the reality and robustness of the climate-sonority connection, consider objections and some other possible connections with cross-language sonority levels, and propose directions that further research on the subject might take.

There are connections to be noted between our research and some very familiar linguistic phenomena. Ladefoged (1993) has pointed out that relative sonority can readily be demonstrated by saying various sounds—at the same loudness of articulation—to an acquaintance some distance away. It will be "much easier" (p. 245), for instance, to hear the most sonorous vowel, [a], than the least sonorous, the [i]. As distance between speaker and hearer is increased, high sonority levels, more audible at a distance, thus assume heightened importance in carrying intelligible messages. Speech sounds differ in their sonority and hence in their carrying power in ways that are well understood. Societies differ in their daily and seasonal cycles of social activities, and in the degree to which the activities are accompanied or regulated by speech, which is sometimes carried on at close range and otherwise at greater distances and in varying physical environments. We believe that this diversity of resources and variation in patterns of use, viewed as a process operating at all times in societies and in the phonetic systems of their languages, may help to account for differential mean sonority levels in the languages of the world. To repeat, we posit that distal oral communication occurs more often in warm/hot than in cold climates. Like the nature and use of many material artifacts of a culture, the nature and location of many activities, including food processing, sociopolitical affairs, ritual observances, leisure pursuits, and personal hygiene, may be influenced by daily temperatures: In warm climates, much of daily life is carried on outdoors due to equable ambient temperatures, but in cold areas, in the face of seasonally low temperatures, these activities often are allocated to indoor settings. (Obviously, some endeavors, such as those directly involving food production and food collecting, will be pursued outdoors without regard to climate.) Speaking in outdoor settings will often entail transmission of messages over distances greater than in the typical indoor case of proximity between speaker and hearer. High sonority would be functionally beneficial in distal interactions, making for a speech signal with more carrying power, thus helping preserve audibility and intelligibility. The possibility that selective pressures could be placed on traits of speech accords with the position of primate ethologists, who look to considerations of dispersal and to the functional and acoustic character of long-distance and short-distance calls (C. H. Brown & Gomez, 1992). Thus, with such theoretical assumptions in mind, we hypothesize that phonetic sonority will be found to correlate with average outdoor temperatures.

CLIMATE CODING AND SELECTION OF SAMPLE CULTURES

A sample of 60 societies was taken from the HRAF Probability Sample Files (Naroll, 1967). The cases were geographically stratified and chosen to represent the 60 macrocultural areas of the world. The restriction that only one society be selected per culture area was adopted to minimize the possible effects of both historical relatedness and diffusion of the selected cultures and their languages (Ember & Ember, 1999). For purposes of supplementary testing, and especially to increase the number of cold-climate cases available, an additional 33 cases were added. Because many of the latter represented large phyla, such as Indo-European and Sino-Tibetan, they also opened possibilities for hypothesis testing *within* language families (see Munroe & Silander, 1999).

Coding for climate—which was confined to those areas where a language has been "traditionally" spoken—followed previous research (Munroe et al., 1996), with one exception. As before, a *cold* month was defined as a month in which mean daily temperatures reached 10°C or lower. The present study, however, has expanded the earlier climatic typology of *warm/moderate* (up to four cold months) and cold (five or more cold months) to include a middle level. The new categories are *warm/hot,* in which there are no cold months in the year (scale-point = 1); *some cold,* in which there are 1-4 cold months (scale-point = 2); and cold, in which there are at least five cold months (scale-point = 3), roughly November through March in the Northern Hemisphere. Due to the probable operation of threshold climatic effects (Whiting, Sodergren, & Stigler, 1982), no larger values were assigned for cold months numbering above five. Altogether, 39 cases were coded as warm/hot, six as some cold, and 15 as cold. This new classification has enabled us to look into possible associations between sonority and a moderate degree of cold. Our analyses also include testing of a linear association based on the precise number of cold months.

Two small changes were made in the climate scores for specific societies. The Khasi, earlier classified on a *doubtful* basis (Ember & Ember, 1999; Munroe et al., 1996) as having no cold months, were recoded as having one cold month per year, this judgment being based on Gurdon's (1914) description, which included references to "winter" (p. 40) and "winter crop" (p. 44), to the month of January as "the coldest in the year" (p. 191), and to Khasi use of fire "in order to keep themselves warm in this month" (p. 191). The Mescalero Apache, earlier classified as having four cold months per year, were recoded as having five cold months, this decision being based on weather-station reports from six areas inhabited by the Mescalero. The mean number of cold months for these six stations was 4.7. (Multiple weather-station reports were collected wherever possible for all cases in which a societal area, along with its corresponding language, was extensive.)

LANGUAGE DATA

For each sample society, a list of up to 200 words was compiled (overall mean number of words per language = 118). The primary source consulted was HRAF Category 192, *Vocabulary* (Murdock et al., 1987), with informal search made of other ethnographic categories for additional words. (Further details on the word lists can be found in Munroe et al., 1996, 2000; Munroe & Silander, 1999.)

Sonority, which we previously assessed with three indices of various vowel and consonant sounds (Munroe et al., 2000), is measured here by means of a scale of relative phonetic power. Fourteen classes of sounds, ranging from the most powerful, the low back vowel sounds, to the least powerful, the stop consonants, were used to assign points to all sounds in the word lists of each of the 60 languages in the sample, plus the languages in the supplementary sample. Point scores were assigned for approximately 45,000 discrete sounds in the original sample and for an additional 25,000 sounds in the supplementary sample.

We derived the sonority scale used in this article from data reported in Fletcher (1929/1953, pp. 82-88). Although this source is, as far as we know, the best available for our purpose, it is presented here as a working expedient, not as a final statement. The organization and original values of Fletcher's Table 7a (1929/1953)

TABLE 1
Relative Phonetic Powers of American English Sounds

ó	[ɔ]	680	ū	[u]	310	ch	[tʃ]	42	k	[k]	13
a	[a]	600	i	[ɪ]	260	n	[n]	36	v	[v]	12
o	[ɘ]	510	ē	[i:]	220	j	[dʒ]	23	<u>th</u>	[đ]	11
á	[æ]	490	r	[ɹ]	210	zh	[ʒ]	20	b	[b]	7
ō	[o:]	470	I	[l]	100	z	[z]	16	d	[d]	7
u	[ʊ]	460	sh	[ʃ]	80	s	[s]	16	p	[p]	6
ā	[e:]	370	ng	[ŋ]	73	t	[t]	15	f	[f]	5
e	[ɛ]	350	m	[m]	52	g	[g]	15	th	[ϴ]	1

are reproduced here as Table 1, with a changed title and the addition of the corresponding International Phonetic Association (IPA) symbol following each of the ad hoc transcription symbols he used in the book. Note that these values are for American English and were in turn based on research carried out by Sacia and Beck (1926). The scale values are multiples of the lowest value, that of the voiceless apico-dental fricative.

As Fletcher (1929/1953) wrote, "The open vowels ó, a, o, and á have the largest phonetic powers. The diphthongs are not given but they have about the same power as the vowels which compose them" (p. 86). He then noted that each succeeding phonetic class has less phonetic power on his scale. We followed his example, assigning a single value to each sound in a class but using a scale whose maximum value is 100. After some discussion, we reassigned one of his "low vowels" to the category of nonback (i.e., front or central) mid vowels: the vowel of *ton* valued at 510 in his table. We think that this value may have resulted from a choice of "standard" speakers by Sacia and Beck (1926) pronouncing what would now seem an actorish or British style of neutral vowel [ʌ], lower and farther back than its American counterpart. This might well have seemed uncontroversial in the 1920s. However that may be, we assigned the mid-central unrounded vowel of contemporary American English a value of 69 on our scale rather than the 100 it would have received if we had followed Fletcher on this point. Phonetic segments from data on other languages were given scores corresponding to each item's phonetic class membership as best we could determine it.

TABLE 2
Sonority Scale

Class Label		*Scale Value*	*Examples*
A	(low vowels)	100	[a, ɔ, æ]
O	(mid back vowels)	80	[o]
E	(mid nonback vowels)	69	[e, ɛ, ə]
U	(high back vowels)	65	[u]
W	(high back semivowels)	43	[w]
I	(high nonback vowels)	41	[i, ɪ]
R	(rhotic consonants)	36	[ɹ]
Y	(high front semivowels)	27	[j]
L	(lateral sonorants)	17	[l]
N	(nasal sonorants)	9	[m, n, ŋ]
S	(voiceless fricatives)	4	[f, s, ⊖]
Z	(voiced fricatives)	3	[v, z, đ]
D	(voiced stops)	2	[b, d, g]
T	(voiceless stops)	2	[p, t, k]

The class label, scale value, a brief phonetic description, and some examples for each class are shown in Table 2. We are aware that the two stop classes have, so far, the same value. Long vowels, affricate consonants, and other complex sounds were resolved into sequences for counting.

Such a scale should be based on a large body of acoustic measurements of a number of speakers of each language in the sample using modern instruments and appropriate statistical tools. There should be comparisons of the acoustic energy output levels and patterns in speech meant to be understood at normal distances and also at longer distances. We hope that someday such data will be collected and published. Here, we have done what we can, borrowing measurements made long ago for a small sample of American English speakers and using them as the basis of a scale of relative sonority for basic articulatory categories, which we then applied to data for other languages based on published transcriptions. These transcriptions themselves had to be interpreted and, in effect, translated into these standard articulatory categories. We have been careful to apply the scale consistently for each language in the sample. For all its shortcomings, compared with what we wish for, we believe this to be the best we can offer.

RESULTS

The application of the scale to data is straightforward and has obvious connections with syllable structures. A very high sonority average, near 50, will usually appear in languages with a large proportion of alternating consonants and vowels (i.e., CV syllables) and few consonant clusters. For example, the Tongan word *lave* "speech," "poem," which is made up of two CV syllables, would be scored as ([l] = 17 points) + ([a] = 100 points) + ([v] = 3 points) + ([e] = 69 points)/4 items = 47.3. By contrast, the English word *handful*, with a consonant cluster and no CV syllables, would be scored as points ([h] = 4 points) + ([æ] = 100 points) + ([n] = 9 points) + ([d] = 2 points) + ([f] = 4 points) + ([ʊ] = 65 points) + ([l] = 17 points)/7 items = 28.7. These two instances have been chosen because they illustrate typical high-value and low-value words, and because Tongan, at 47.2, received the single highest overall sonority score among the sample societies, and English, at 32.9, received nearly the lowest overall sonority score.

The Pearsonian correlation between climate-type and sonority scores was –0.63 ($p < .001$, $N = 60$).[1] High sonority scores tended strongly to occur in warm climates to the extent that the 21 highest scores were associated with languages located in warm/hot areas. At the other end of the scale, eight of the nine lowest sonority scores belonged to languages located in cold-climate zones. If we disregard the climate-type categories and simply test sonority scores by total number of cold months, we obtain a slightly weaker but similar r value of –0.57 ($p < .001$, $N = 60$).

When the cases are sorted by world culture regions (Murdock, 1957), as in Table 3, we see a robust association: In all regions in which climate-type variation occurs, the mean sonority level falls as the climate categories move from warm/hot to some cold to cold ($p = 0.002$).[2] Further regularities can be seen: In all six regions, the warm/hot cases attain a mean sonority level well above the sample median of 40; in the three regions in which there are cases of some cold, the mean sonority scores hover near 40; and in the four regions in which there are cases of cold, the mean sonority scores are below 40. (The Ona of Tierra del Fuego, rated as cold in the South American region, come close to creating a single-case exceptional category with their relatively high score, which nevertheless remains below 40.)

Exceptionally bad cases are rare. Of the 39 languages in the warm/hot regions, only one (the Tzeltal) displays a score below the

TABLE 3
Sonority Scores and Climatic Types by Region for World Sample (N = 60)

	Region											
Climate	*Africa*		*Circum-Mediterranean*		*East Eurasia*		*Insular Pacific*		*North America*		*South America*	
Warm/Hot												
	Ashanti	46.8	Somali	45.3	Sinhalese	43.7	Tongan	47.2	Tarahumara	44.8	Caraja	46.3
	Dogon	45.2	Teda	43.9	Burmese	43.1	Toradja	45.5			Pemon	45.6
	Masai	43.2	Hausa	43.5	Santal	42.3	Lau Fijian	44.0			Cagaba	44.2
	Bemba	40.7	Shluh	39.3	Andamanese	40.4	Kapauku	43.5			Yanoama	43.2
	Luganda	40.5			Central Thai	37.9	Trobriand	42.5			Cuna	43.0
	Kpelle	39.7			Vietnamese	36.0	Aranda	42.4			Caingang	40.0
	Lozi	39.7					Ifugao	41.2			Toba	39.2
	San	39.1					Trukese	38.0			Mundurucu	39.0
	Fang	38.0					Iban	37.2			Tzeltal	33.7
	Tiv	37.9										
	Mean	41.1	Mean	43.0	Mean	40.6	Mean	42.4	Mean	44.8	Mean	41.6
Some Cold												
			Rwala	40.7	Pashtun	40.9					Aymara	39.9
			Lebanese Arabic	40.4	Khasi	35.4						
			Greek	40.0								
			Mean	40.4	Mean	38.0					Mean	39.9

(continued)

TABLE 3
(continued)

Climate	*Region*											
	Africa		*Circum-Mediterranean*		*East Eurasia*		*Insular Pacific*		*North America*		*South America*	
Cold												
			Serbo-Croatian	36.3	Yakut	36.7			Fox	42.3	Ona	39.0
			Lappish	33.6	Korean	34.1			Iroquois	39.9		
			English	32.9	Chukchee	31.9			Ojibwa	39.0		
									Tlingit	38.0		
									Klamath	34.7		
									Copper Eskimo	34.6		
									Blackfoot	34.3		
									Mescalero	31.1		
			Mean	34.4	Mean	34.2			Mean	36.7	Mean	39.0

NOTE: Climate code: warm/hot = 0 months with average temperature dropping to 10°C (50°F) or lower; some cold = 1-4 months with average temperature dropping to 10°C (50°F) or lower; cold = 5 or more months with average temperature dropping to 10°C (50°F) or lower.

overall mean of the languages in the cold regions. And of the 15 languages in the cold regions, only one (the Fox) displays a score above the mean of the languages in the warm/hot regions.

Beyond the difference in overall sonority levels of warm- and cold-climate languages, we find expected variation in the proportions of vowels, sonorants, and nonsonorant consonants: The warm-climate languages achieved higher mean scores on proportions of both vowels and sonorants, and the cold-climate languages achieved higher mean scores on the proportion of nonsonorant consonants (all differences at the 0.01 level or stronger, by the *t* test). Additionally, within the category of vowels, the most sonorant class, the A, occurred more frequently in warm-climate languages, whereas the least sonorant class, the I, occurred more frequently in cold-climate languages (both differences significant at the 0.01 level). And of the 14 discrete sound classes in our scale, six differed significantly by climate type and three others differed at a marginally significant level.

The sonority mean for all cases (Table 3) coded as warm/hot (N = 39) was 41.7, and that for all cases coded as cold (N = 15) was 35.9. The difference of 5.8 points equates to an average advantage of 16% in sonority in the languages of warm/hot versus cold zones of the earth. Moreover, the range of all sample scores, from Tongan at 47.2 down to Mescalero at 31.1, was only 16.1 points; thus, the difference between warm- and cold-climate means, amounting to more than one-third of the range, can be seen as substantial from that perspective as well.

Turning to the expanded sample of 93 cases,[3] we find that the correlation between climate-type and sonority scores, at –0.66 ($p <$ .001, N = 93), was slightly higher than with the primary sample.[4] This larger sample allowed us to examine climate and sonority covariation within language families.[5] For two families, Indo-European and Sino-Tibetan, there was a minimum of 10 languages with at least one language located in each of the three climatic zones. For Indo-European, the means were 43.7 for the hot/warm zone, 39.3 for the some cold zone, and 34.1 for the cold zone. The corresponding scores for Sino-Tibetan, 39.0, 37.3, and 37.2, were directionally correct, but differences among zones were minimal. In six additional language families for which there was climatic-type variation, there were four in which the warmer-region means exceeded that of the colder-region means, and there were two cases that went against prediction. The overall probability that the rank order of means according to climate-type would align with prediction to this degree was less than 0.01.[6]

The sonority scores of national languages were more likely to be below the median than were other scores (two exceptions were Sinhalese at 43.7 and Burmese at 43.1). It might be thought that the sonority values of national-language cases would be low due to cultural-complexity factors. Low sonority scores typically indicate the presence of a large proportion of consonant clusters, that is, complex syllables, and these might be associated with the overall complexity of cultures. Yet scores for cultural complexity were uncorrelated with sonority, $r = 0.10$, $N = 38$, *ns* for the main sample, and $r = -0.14$, $N = 53$, *ns* for the expanded sample.[7] Most of the high-complexity societies, however, belong to Indo-European and Sino-Tibetan, and their average sonority scores may simply represent phyla baselines that are due to some still unknown factors.

DISCUSSION

In previous research, Ember and Ember (1999) presented evidence linking early experience, specifically body contact of infants with caretakers, to a putative preference for regular rhythm, which in turn was expected to account for the existence of sound regularities in languages. In their most recent work on the subject, Ember and Ember (2000) have agreed in part with our position concerning sonority while also continuing to argue for the importance of early body contact ("baby-holding," in their terms). Here, we analyze their variable of baby-holding in relation to our current sonority scores. The Pearsonian correlation between degree of baby-holding and sonority scores was 0.40, $p < 0.002$, $N = 50$. Although baby-holding was a weaker predictor of sonority than was climate, its status as a second possible determinant of sonority prompted us to undertake a stepwise multiple regression analysis with the purpose of elucidating which variable was more important. The analysis revealed that only climate was a significant predictor in the regression equation, with a multiple R of 0.63 ($p <$ .001). (For baby-holding, Beta = 0.01, *ns*.) The value of R^2 was 0.39, and the adjusted R^2 was 0.38.

We can also briefly report that other variables showing earlier promise as predictors of phonetic regularities, to wit literacy and number of syllables per word (Ember & Ember, 1999; Munroe et al., 1996), were not significantly related to our current sonority scores.

Size of phonemic inventory was also unrelated to sonority levels. As another hypothesis, the regularity of scores within climatic-geographic regions might be interpreted as consistent with a liberalized *Sprachbund* hypothesis (see Weinreich, 1958, for discussion). That is, geographically associated languages—even if of different families—could converge in sonority due to long-term historical contact. To assess the likelihood of such a possibility, we divided the sample into 30 sets of two cases each, the sets being composed of a given society plus the society geographically closest to it. If proximity was indeed an important factor in inducing similarities in sonority levels, then the association between these paired language scores should have been meaningful. The Pearsonian correlation, however, reached only 0.34, a not-quite-significant figure. Because paired languages typically were located in the same climatic zones—and this, given our results, should have improved on any underlying association—the absence of a finding indicates all the more that a Sprachbund effect is not operative. Note also in this connection a strikingly weak correlation of mean sonority with longitude compared with latitude: Whereas latitude, as a rough proxy for climatic area, was correlated with sonority scores at –0.57, longitude and sonority were unrelated at $r = -0.04$. Thus, climate remains the sole known variable to which any claim of predictive power can be attributed.

It is important to understand that our hypothesis does not imply that high-sonority values are disfavored in cold climates, only that low-sonority values are disfavored in warm ones, that is, where presumably more frequent moderate dispersal of interactants makes speech communication beyond ordinary conversational distance a commonplace event during a substantial portion of the year. Once again, we do realize that in all climates, people often interact verbally at close range, and also that in any climate, people may engage in solitary or silent activities, or may carry out collective activities at interpersonal distances too great for intelligible naturally transmitted speech. But these cases lie outside the envelope of acoustic, climatic, linguistic, and behavioral factors that we consider here.

THE PERSPECTIVE OF FIELD BIOLOGY

Our conceptual model is perhaps most like that of population biology. Indeed, in biology there are a number of well-known correlations between climatic and somatic variables. Allen's Rule (Allen, 1877) asserts that the appendages of cold-climate animals are shorter than those of related species in warm climates; Bergmann's Rule (Bergmann, 1847) notes that cold-climate animals have smaller surface areas in relation to their body mass compared with warm-climate animals, whereby the cold-climate animals retain body heat better and the warm-climate animals radiate it better. Human body proportions in long-established warm- and cold-climate populations fit this rule also as one of several possible adaptations to cold.[8] Nor is it controversial to assert that animal behavior adapts to environmental differences. Instead, it is a long-accepted finding of ethological research that communicative modalities and behaviors are selected or designed for success in the specific habitat and not just by primates but also by other mammals, birds, fish, and insects. Finally, there is a complex and pervasive influence of climate on virtually every aspect of culture, which is so pervasive that we tend to take it for granted.

The broadest disciplinary context within which we can place our work is that of field biology, especially primate ethology. Ethologists have much to offer us. They are accustomed to studying communication as it takes place within and between bands of individual subjects moving about in various environments. Unlike linguists, they typically study their subjects outdoors, often while on the move with them. Their framing of research issues, their terminology, and their tools will be useful for research on speech communication among gathered or dispersed humans. Resemblances in communicative behavior among primates can be appreciated by noting certain types of vocalization whose forms and functions are more or less the same for all of us: roars of rage and intimidation, screams of pain or alarm, threatening growls, and grunts of communion, all of them apparently used both seriously and in play. In relation to their subjects, ethologists are outsiders observing alien social behavior in an effort to understand its orchestration and meaning. For our part, we freely concede that linguistics is among other things a branch of primate ethology, one in which the researchers and their subjects at least sometimes enjoy a privileged level of understanding.

Field ethology also offers a ready-to-use framework of variables for the measurement of sound propagation and attenuation, and for experimental tests of signal audibility and intelligibility in the study of outdoor vocal communication.[9] An important part of this framework is the characterization of what is called *habitat* *acoustics.* The sound spectrum of human speech includes frequencies ranging upward from about 100 Hz (the fundamental frequency of the vibrating vocal bands). Most of the sound energy of speech is concentrated in bands between 100 and 3000 Hz. Some consonantal articulations produce bursts whose frequencies range as high as 12000 Hz. The audible signals of many other animals also fall within the same range of frequencies and in some cases the same energy levels, making the conceptual framework and comparative data of ethological research immediately useful in similar research on outdoor communication using language.

The original energy levels of the pressure waves making up acoustic signals propagated in air grow weaker as the sound waves spread outward from their source in three-dimensional space. This geometric weakening is called *attenuation*. Sound energy in a signal is also subject to specific kinds of interference: masking by ambient noise, absorption by surfaces and dispersed particles, and reverberation of energy reflected from environmental surfaces and interacting with the original signal. The temperature, humidity, and turbulence of the air itself are major factors; in general, however, the air medium ensures that higher frequencies are attenuated more rapidly. Other materials in the environment surrounding the source, such as landforms, manmade structures, vegetation, soil and rock, and water as vapor, rain, ice, or snow, all contribute to the alteration of the original signal in complex ways. Taken together, these additional factors constitute what is called *excess attenuation*. Although isolating and modeling the individual components responsible for excess attenuation are difficult, measuring their combined effect on a specific signal between two points in the habitat is relatively easy.

The total volume of space within which a signal is audible to potential receivers is called its *active space*. This usually has a size and a shifting, complex shape that is determined by the many acoustic variables of the original signal interacting with the physical properties of the habitat. Near the limits of its active space, a vocal signal is presumably just recognizable as such. For our purposes, however, the notion of a speech signal's active space must be supplemented by considerations of its *intelligibility* rather than just its audibility. To hear a primate conspecific's loud call may be informative in itself, depending on circumstances, but to achieve effectiveness in speech communication, it is necessary also to understand at least something of what is being said. We therefore propose the additional notion of a volume of space enclosed within the active space of a speech utterance, in which a gradient value of signal intelligibility could be measured. Once again, we note obvious connections with familiar adjustments in the properties of speech when aimed at a distant listener, such as repetition and prolongation, both increasing redundancy and thus promoting intelligibility despite attenuation (enlarging the intelligible space) and increased loudness, enlarging both the active and intelligible spaces of the signal. An obvious adaptation of ethologists' field playback experiments could be made by introducing a more complex interpretation of the signal perceived by the subjects, asking them what was said and what it meant, and thus taking advantage of the enviable advantage in humans' access to the meanings of human (rather than nonhuman) speech communications. Such research would have much in common with laboratory phonetic experiments except for the substitution of a natural environment for the laboratory and the consequent addition of manifold variables of habitat, distance, and language. For a glimpse of the complexities of such work and an excellent model to adopt, see Waser and Waser (1977) and Waser and Brown (1986), in which habitat acoustic variables and carefully simulated signals representing the vocalizations of a number of similar primate species were compared throughout three African habitat types (rainforest, riverine forest, and savanna) with systematic attention to the elevation of the source, time of day, direction (relative to winds) and distance. As for the intelligibility of human speech, abundant laboratory phonetic research already carried out on masking, distortion, clipping, and other intelligibility variables under the sponsorship of telephone laboratories (again, see Fletcher, 1929/1953, for models), together with the design of ethological studies, provides technical and design baselines for similar field studies of speech.

REACTIONS, IMPROVEMENTS, EXTENSIONS, AND CONNECTIONS

Our experience in presenting earlier versions of our work suggests that anthropologists and linguists are primed to reject out of hand proposed correlations between climate and social, cultural, or linguistic features. There should of course be no confusion of our tentative hypothesis with the old climatic determinisms. Beyond the particular gradient acoustic properties associated with sonority and with attenuation[10] and their implications for the intelligibility of speech at a distance, no claims for one sound system over another are expressed or implied here. Our tools are statistical, and our views are correspondingly nuanced and tentative.

We are well aware that a correlation does not imply a causal relation. We make no claim of logical necessity: We merely offer a possible pattern of influence for consideration. Nevertheless, there *is* a correlation here whose strength is significant, and we believe that *plausible* reasons for it merit exploration. We invite your help with critical refinements of the assumptions, data, and analysis at each link in the chain of argument we present here. We have anticipated some objections ourselves and responded to certain others, which we will list briefly here, before moving on to consider ramifications and additional opportunities for research.

Enlargement of the set of linguistic data, both as to range of languages and depth of coverage, is clearly desirable, as is a continuing refinement of the sonority scale we have constructed. We recognize that the data set we are using is far from ideal. In particular, the phonetic skills of the compilers of the wordlists and texts in the HRAF collection appear to vary widely. The properties in question, however, asserted themselves at the same levels when we matched HRAF data scores language for language against a subset of our overall body of data that was gathered and transcribed by trained phoneticians and published in the current *Handbook* of the International Phonetic Association (1999).[11]

We assume that the orthographic renderings in our word lists stand for some expected and approximately specifiable clump of phonetic features defining one or more segments, each of which we have then converted to a sonority value. The scale was applied consistently, but we recognize that it raises questions, perhaps seeming at once too precise in some respects and too crude in others. Fletcher's (1929/1953) measurements were of American English speakers only. Cross-language variation in phonetic inventory, such as that implicit in the 22 different fricatives listed in the IPA (Ladefoged, 1993), is handled in a seemingly procrustean manner. Nevertheless, to apply a statistical analogy from analysis-of-variance terminology, we believe that between-class variance among our sound classes is far greater than the within-class variance. Here, too, we would welcome genuine, empirically validated improvements. We note, however, that our classification agrees with other sources at least in the rankings of sound types, such as Fry (1979). As a working sonority scale, it includes more intervals than other published scales, many of which use only a few categories and admittedly arbitrary quantities. We may have inadvertently misclassified some exotic sound types, but that too remains to be demonstrated, along with the magnitude of any resulting distortion in the results. Refinements in the scale to make it more accurate and more comprehensive through broader sampling and more accurate measurements of acoustic energy would be most welcome.[12]

Partly or wholly unknown culture-historical and environmental variables might have effects on our results, including microclimatic differences within larger zones, recent cultural changes affecting the habitual dispersion of interactants, their customary readiness to speak and listen to each other under specific conditions, and many, many other possibilities involving cultural changes perhaps too recent to be reflected in compensatory sonority differences. We have as yet no answers to such questions or any way at present to assess the relative importance of each to our conclusions. For instance, we make no claims here about how comprehensive or how lasting a cultural (or climatic) difference must be before there might be a corresponding adaptive change in mean sonority values in accordance with our hypothesis. These are among many interesting questions that might be approached through more detailed studies of carefully selected sets of languages at different stages in their histories, and in studies of the external histories of their speakers. We do not pretend to have answers to these questions now, and indeed we believe that some may never be answered.

In some cases, as in recent migration by a people to a new and different geographic and climatic area, sonority scores might better reflect historical circumstances than current conditions, and this possibility should be looked into as further inquiry is undertaken. For the climatic variable, other factors besides temperature, for example, humidity, rainfall, cloud cover, and the vegetative environment, could all affect habitat acoustics and ideally would be taken into account in considering outdoor vocal communication. In addition, temperature alone may not prove the best way to evaluate the degree to which peoples engage in outdoor activities. For instance, the Ona occupy a rigorous, demanding habitat at the southern tip of South America and are rated as having 12 cold months per year. But all their activities are performed "outdoors" because the Ona construct only rude vertical windbreaks and even sleep in the open (Cooper, 1946; McEwan, Borrero, & Prieto, 1997).

An experimental research effort might provide valuable insight into our questions, especially those surrounding distance and speech communicability. Nettle (1994), analyzing a previously collected data set, has found that speakers of languages with high vowel-consonant ratios (i.e., high sonority) use lower speech volume in conversation than do speakers with low vowel-consonant ratios. This regularity implies that for a language like English, with its plethora of consonant clusters (in common words such as *plans*, *prank*, and *strict*), ordinary outdoor conversation could not be conducted as facilely as would be the case for a language like Tongan. Nettle's finding is consistent with the arguments and the results set forth in this article, and it points to a type of inquiry that could be applied to our general hypothesis. Other experimental conditions involving cross-language and intra-language variation, as well as speech volume and distance, could provide a basis for understanding the main features of natural phonetic systems.

SUGGESTIONS FOR FURTHER RESEARCH

Every component of the research program sketched or implied here should be regarded as an open invitation to additional refinement and testing. We welcome suggestions and additional studies, whatever their outcome, as a way to test and clarify what we have considered so far. Broader inventories of sound types, improved measurements and scaling of the acoustic energy properties of sound types in connected speech, and larger data sets, both in number of languages and varieties and in the size of the sample of each, are obvious starting points. More confidence in the sonority scale through careful measurement of recorded speech samples is another urgent need.

The testing of intelligibility outdoors under varied conditions and distances and in many types of habitat provides an opportunity for novel research. We rejoice at the thought of countless sophomores all over the world engaging in healthy, productive outdoor activities involving audio equipment. Cross-cultural observational studies of how and when people speak and listen to each other outdoors, in relation to specific cooperative activities, fit into the program as well. Information about habitual behavior, including language use, during everyday subsistence activities is surprisingly thin in most anthropological field studies.[13]

There are even indoor components of this potentially vast enterprise. Gleaning published cultural and culture-historical information on annual cycles of activities and the locally relevant climatic data for each of the territories inhabited by speakers of the sampled languages are two important axes of refinement in the program. Finally, there are further possible benefits from the creation or, in some cases, the renewal of connections of theory and practice between linguistics and other social science disciplines, conspicuously including field biology, at what might properly be called the ground level.

It is obviously still possible that the documented relation between climate and sonority will, in the end, be accounted for by some variable other than frequent distal communication. What may ultimately prove explanatory could be another variable that is meaningfully correlated with climate or even a variable that has only an adventitious association with climate. But the regularities shown herein do indicate fairly conclusively that the geographically skewed distribution of phonetic sonority presents a scientific puzzle worthy of attention.

NOTES

1. This association was as predicted. But, as noted in the introduction, the original study in our research program found that CV syllables also were related to climate, $r = -0.40$, $p = 0.003$, $N = 60$. Nevertheless, partial-correlation analyses indicated that with CV frequency controlled, climate and sonority remained strongly related, at $r = -0.53$, $p < .001$, $N = 60$, whereas with sonority controlled, the relation between climate and CV frequency fell to 0.00, *ns*, $N = 60$.

2. The probability level for this set of outcomes was calculated as follows. In two regions (Africa and Insular Pacific), all sonority scores belonged within the warm/hot climatic type and were thus without variability in this respect. In three regions (Circum-Mediterranean, East Eurasia, and South America), there were sonority means for each of the climatic types, warm/hot, some cold, and cold; thus, six possible ways the means could be ranked; therefore, a one-sixth chance that in any region, warm/hot > some cold > cold; and, therefore, a $(1/6)^3$ or 1/216 probability that this would occur in all three regions. In the remaining region (North America), there were sonority means for two climatic types, thus a one-half chance

that warm/hot > cold. The combined probability of 1/216 x 0.5 equals 1/432, or 0.002.

3. The additional cases, with climate-type (scored from 1-3) and sonority score, respectively, were as follows: Araucanian 2, 37.6; Cantonese 1, 35.2; Carrier 3, 29.7; Chilcotin 3, 29.2; Chipewyan 3, 33.5; Eyak 3, 31.9; French 3, 36.9; Galice 3, 38.4; Garifuna 1, 50.1; Garo 1, 38.8; German 3, 33.5; Gurung 3, 37.0; Hopi 3, 38.6; Italian 2, 38.6; Japanese 2, 40.1; Jivaro 1, 41.6; Lepcha 3, 37.8; Mandarin 3, 35.0; Navaho 3, 29.9; Newari 2, 39.5; Nootka 3, 33.4; Norwegian 3; 31.1; Nosu 2, 35.1; Portuguese 2, 39.7; Russian 3, 33.7; Sgaw 1, 39.0; Spanish 2, 39.0; Tanaina 3, 32.0; Tibetan 3, 39.1; Trumai 1, 39.0; Tucano 1, 42.3; Yahgan 3, 42.5; Yaruro 1, 36.3.

4. As reported above, in the original sample the difference between the means of cases in the hot/warm- versus cold-climate areas was 5.8 points (41.7 to 35.9). For the additional 33 cases in the supplementary sample, the difference between means was almost identical at 5.7 points (40.3 to 34.6).

5. The classification of languages was based on Ruhlen (1991). The authors will furnish on request a list of the language family to which each sample member was assigned.

6. The probability level for this set of outcomes was calculated as follows. For Indo-European and Sino-Tibetan, there were sonority means for each of the three climatic types; therefore, a one-sixth chance that in a given language family, warm/hot > some cold > cold; and, therefore, a $(1/6)^2$, or 1/36, probability that this ranking would occur in both families. In six families (Afro-Asiatic, Altaic, Andean Amerind, Central Amerind, Northern Amerind, and Austroasiatic), there were sonority means for two climatic types and (according to binomial expansion) an 11/32 chance that two or fewer warmer-region means would be lower than their corresponding cooler/colder region means. The combined probability of 1/36 x 11/32 equals 0.0095.

7. Murdock and Provost (1973) provided complexity scores (composite scale) for 47 cases in our samples, and we have assumed high complexity, and assigned corresponding scores, for six national-language cases.

8. The 19th-century philosophers of history and culture (from temperate climates) who believed that temperate climates best fostered civilization were anticipated by much earlier works such as Jean Bodin, *Method of History* (1556), and Montesquieu, *De l'Esprit des lois* (1748). This tradition, we repeat, has no connection with our work. The original sources for these are Allen (1877) and Bergmann (1847). For an overview of human physiological adaptations to climate, see Roberts (1978).

9. The American National Standards Institute (1995) and Sutherland and Daigle (1998) give general background, references, and formulae for calculating sound propagation and for atmospheric and some other environmental excess attenuation variables. Specific factors contributing to excess attenuation and overviews of the acoustic properties of some types

of habitat are covered in many sources. For our understanding of these issues, we relied especially on Aylor (1972); Dickinson and Doak (1970); Embleton (1963); Henley and Hoidale (1973); Marten and Marler (1977a); Marten, Quine, and Marler (1977b); Michelsen (1978); and Rasmussen (1981).

In forest habitats, many animals, including primates, apparently tailor the spectra and temporal organization of their various calls to exploit whatever sound propagation window is found in their habitat. Often, these windows reach no higher in frequency than 3500 or 4000 Hz. For example, see C. H. Brown and Gomez (1992), T. J. Brown and Handford (2000), and Morton (1975).

10. Clements (1990) retraced the historical development of sonority-based and aperture- (or stricture-) based views of the segment and the syllable, and attempted to reconcile them, starting with the 19th century. He stated his own sonority sequencing principle as follows: "Between any member of a syllable and the syllabic peak, only sounds of higher sonority rank are permitted" (1990, p. 285). He recognized that this principle, which in one form or another has been proposed by many linguists through this entire period, has quite a number of exceptions "at the surface," depending on the language, the particular form it takes (regarding sonority plateaus, etc.), and the particular sonority ranking used by each authority. His own treatment placed it at the level of phonological theory with its surface manifestations subject to rules, some of which lead to exceptions. Such a theoretical principle does not seem an appropriate basis for rejecting a sonority scale based on measurements because it might at times contradict the predictions of a principle embedded in a particular approach to phonology. Indeed, the attitude that a theoretical principle stands above revision based on data seems objectionable in principle.

In establishing our perspective on the syllable and related matters, we have relied mainly on the account of the complex and hierarchical orchestration of muscular activity in the torso, throat, and mouth during speech as discussed in a famous article by Ladefoged (1967). Other familiar aspects of phonetics and the syllable relevant here are covered in Janson (1986), Ladefoged (1993), Lindblom (1984, 1986), MacNeilage (1998), and Maddieson and Precoda (1992).

11. Specifically, for 20 languages in our expanded sample, there was available a phonetically precise rendering of a single fable (entitled "The North Wind and the Sun"; see International Phonetic Association, 1999). Our sonority scale, when applied to this controlled data set, yielded scores that were correlated with both our HRAF-derived sonority scores ($r = 0.58$, $p < 0.005$, $N = 20$) and with climatic zones ($r = -0.59$, $p < .005$, $N = 20$). The relation between our sonority scores and the IPA-derived sonority scores was probably weakened by the fact that the expanded sample contained equal numbers of languages in warm/hot versus cooler zones, whereas the

IPA subsample was biased heavily (65% of cases) toward cooler-zone languages, thus reducing the variability of scores.

12. Two reviewers suggested that the presence of lexical tone should contribute to intelligibility over distance. We do not have systematic data on this issue but note informally that the warm/hot zones contain tonal languages like Cantonese, Garifuna, Thai, and Vietnamese. Mandarin, another instance, is a cold-climate case. Furthermore, it is not evident just how lexical tone distinctions would *necessarily* affect mean sonority.

13. A formal attempt was made to use the HRAF archives to gauge elements of social interaction, including language use, during subsistence activities in the sample societies. Reliable inferences could not be drawn due to a paucity of such information in the great majority of ethnographies.

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