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Commentary: The role of language contact in creating correlations between humidity and tone

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Everett et al. (2015) find a that complex tonal languages tend to be found in humid environments a correlation that holds up within different families and parts of the world. Despite the impressive statistical and experimental support for this causal claim, evidence is needed from natural language use, such as Chinese speakers changing their use of tone depending on humidity, before the claim can be considered well supported. There is otherwise a risk that this correlation could be an artifact of history of language families and language contact. To illustrate this, I show in a series of simulations that random selection of languages followed by language contact can create a positive global correlation between tone and humidity with as much as a 83 per cent probability, and a 47 per cent probability of holding within at least two different macro-areas. Language contact is additionally responsible for these correlations holding up when controlling for language relatedness, as I show that when using the random independent samples test employed by Everett et al., their result is still expected by chance as much as 60 per cent to 80 per cent of the time. I further show how contact can create correlations within families by a phylogenetic analysis of the evolution of tone in Niger-Congo and Sino-Tibetan.

1. Appraisal of Everett et al. (2015), and the need for evidence from natural language use

The number of tones that languages use correlates with humidity within five different global areas (Africa, Eurasia, South America, North America, and the Pacific), and within four different language families (Sino-Tibetan, Austro-Asiatic, Afro-Asiatic, and Niger-Congo). This is better statistical support than even for word order universals, which despite having some support when sampling from different macro-areas (Dryer 1992) do not seem to hold consistently within large language families (Dunn et al. 2011).

In addition, the experimental evidence that they cite showing that dry air has an effect on the larynx raises a host of linguistic questions that are worth exploring anyway, even without this global correlation between dryness and lack of tone. Do speakers of Cantonese alter their use of tone in dryer conditions, for example? This may be a realistic expectation, if the effect of desiccated air on the larynx is as strong as it is reported in experiments. China is a natural testing ground for work of this kind, given that varieties of Chinese vary in their number of tones and in their climactic conditions. If Everett et al. are correct that the number of tones in Sino-Tibetan languages has been shaped by humidity, they would have made an important contribution to fields such as the history of Chinese, in explaining how different varieties have changed in their number of tones as people migrated in different environments.

This is an exciting possibility. However, for the remainder of this article, I want to explore a possible historical explanation for how tone could have ended up correlating with humidity, namely the nature of language contact.

2. The worldwide distribution of language families

Language families are not randomly distributed around the world. There tend to be more languages in more humid areas such as west Africa and New Guinea, for example; humidity correlates with number of languages per 30,000 km^2 (Pearson's $r = 0.31$, $P < 0.001$), using data on humidity supplied by Seán Roberts as used in Everett et al.'s paper. This is illustrated by Figure 1, which shows density of languages for every language location in the World Phonotactics Database (Donohue et al. 2013). The size of the stars is proportional at each point to the number of languages within a 100-km radius of that point (typically this is between 1 and 5 in Europe, and as high as 134 in parts of New Guinea).

It is also possible that the geographical distribution of language families is shaped by humidity: to the extent that the spread of languages is sometimes driven by agriculture (Diamond and Bellwood 2003), one would expect some language families to have an origin in humid places and to peter out in dryer environments, potentially shaping the way that tone has spread as well.

This raises the question of whether purely random evolution of tone in language families could cause there to be a global correlation between tone and humidity.

The most basic illustration of this is to choose a small number of languages at random and to assign complex tone to languages around those points. For example, four languages can be chosen at random from languages in the World Phonotactics Database, and for each of those four languages, the nearest fifty languages are assigned complex tone. The remaining languages are assigned lack of complex tone. This was done 100 times and the global correlation with humidity tested in a logistic regression, and also using the random independent sample test that Everett et al. employ in their paper. The parameters were then varied, with the number of randomly selected languages N varying between 4 and 6, and the number of neighboring languages L being 50, 100, and 150.

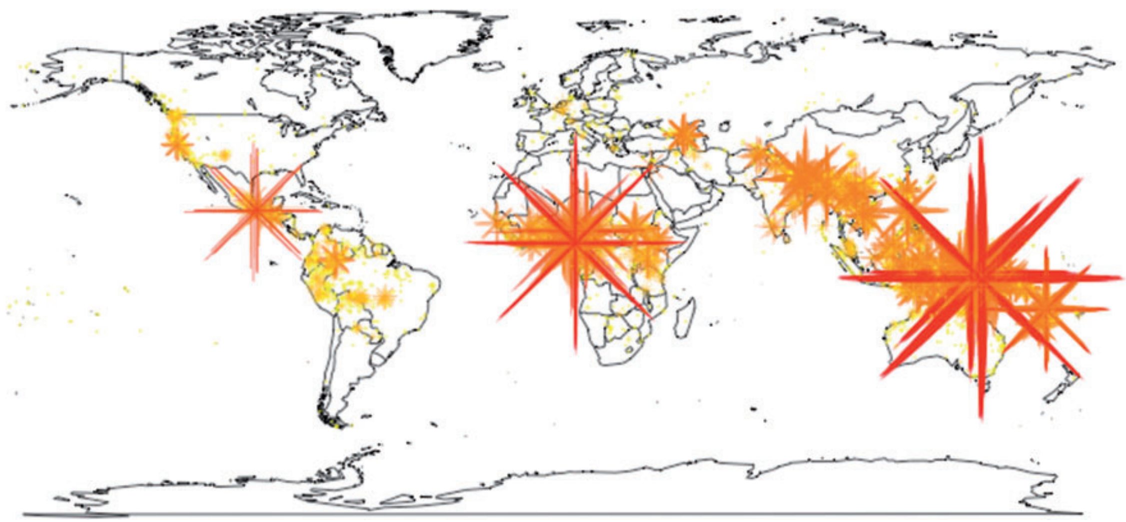

Figure 1. A map of language density, with the size of the star on each point proportional to the number of languages within a 100km radius of that point.

The result was that the number of neighboring languages L was the main determining factor of how likely a positive correlation with humidity was. In the simulations with $L = 100$ languages, between 54 per cent and 55 per cent of simulations resulted in a positive correlation between humidity and complex tone ($P < 0.05$). In simulations with $L = 150$ languages, 48 per cent to 53 per cent of simulations resulted in a positive correlation. In simulations with $L = 50$ languages, only 34 per cent to 41 per cent of simulations resulted in a positive correlation. (The choice of number of random languages chosen N made little difference.)

Everett et al. use a random independent samples test rather than a logistic regression. They sample one language per family in order to control for relatedness, and then compare the humidities of complex tonal languages with non-complex-tonal languages. In some ways, their test is in fact more lenient than a logistic regression; although their test shows that complex tonal and non-complex-tonal differ in their humidities, in a logistic regression this difference is not significant ($P = 0.16$). In other ways, their test may be more appropriate for their prediction; they are predicting that in especially dry environments, complex tonal languages are unlikely to occur. Their main way of testing this is to look at the lowest 15th percentile of humidities in the two groups and compare them, done over 5,000 samples. When I did this with 100 samples, the the lowest 15th percentile of the humidities of the complex tonal languages was always higher than that of the humidities of the non-complex-tonal languages, in line with their prediction.

But how likely is this particular result to occur by chance? Using the same simulation as reported above, I reran the analysis with $L = 100$, $L = 200$, and $L = 300$. The probability of their result occurring in these random simulations is 33 per cent, 45 per cent, and 49 per cent respectively.

I also tested what would happen if L was not a fixed number but was a distance; for example, if tone spread to languages within 500 km of the original N languages. In these simulations, the proportion with positive, significant correlations between tone and humidity jumps up to 81 per cent, and the proportion in which the random independent samples test yields the same result as Everett et al. is 53 per cent.

This result seems to be due to the high concentration of languages in humid areas, making random selections of geographically contiguous languages likely to be found in humid regions. However, many of these languages in these regions are closely related (e.g. there are a lot of Niger-Congo languages in west Africa), making this test perhaps unfair. If instead of choosing languages purely at random they are chosen in a phylogenetically weighted way, then the result changes. The way to do this was to randomly select a language family, and to choose a random path from the root of the family to one of the tips. When this is done, using six randomly chosen languages, the probability of a correlation with humidity is lower, and in fact a negative correlation with humidity is more likely for low values of number of neighboring languages chosen L. With L being 100, 150, and 200, the probability of a positive correlation was 36 per cent, 42 per cent, and 48 per cent, compared with the probability of a negative correlation being 50 per cent, 46 per cent, and 36 per cent. In other words, the probability of a positive correlation increases as the extent of language contact increases. The probability of their result in the random independent samples test is 38 per cent, 33 per cent and 42 per cent respectively. With higher values of L the probabilities increase further.

If instead of a fixed number of languages L tone spreads over a fixed distance of 500 km, then the probability of significant positive association in a logistic regression is 83 per cent, and the probability of their particular result in the random independent samples test is 51 per cent. Over a distance of 1,000 km, the probabilities are 83 per cent and 60 per cent respectively.

In all of these cases, the probability of their result in the random independent samples test (and in the logistic regression) is much higher than normally accepted by conventional significance; in fact, under some models of language contact given above, it is highly likely that tone will correlate with humidity, including after controlling for language family.

Not every linguistic feature is expected to correlate in this way with humidity, but only those that have a high value of L in these simulations, the number of languages that the feature is transmitted to. Linguistic features which become particularly widespread, whether through vertical transmission or through language contact, therefore have the highest probability of showing this correlation. Tone is an example of such a feature, because it is both stable in large language families comprising hundreds of members such as Sino-Tibetan and Niger-Congo, and has also spread by the influence of these large families into neighbouring families in the rest of Africa and southeast Asia, as has been documented for example in the case of the formerly non-tonal languages Vietnamese and Cham acquiring tones (Enfield 2005). These diachronic properties of tone are predicted to cause a positive correlation with humidity whether or not Everett et al.'s causal claim is true.

The global correlation between tone and humidity should therefore be considered a spurious result. The more impressive part of Everett et al.'s results is that

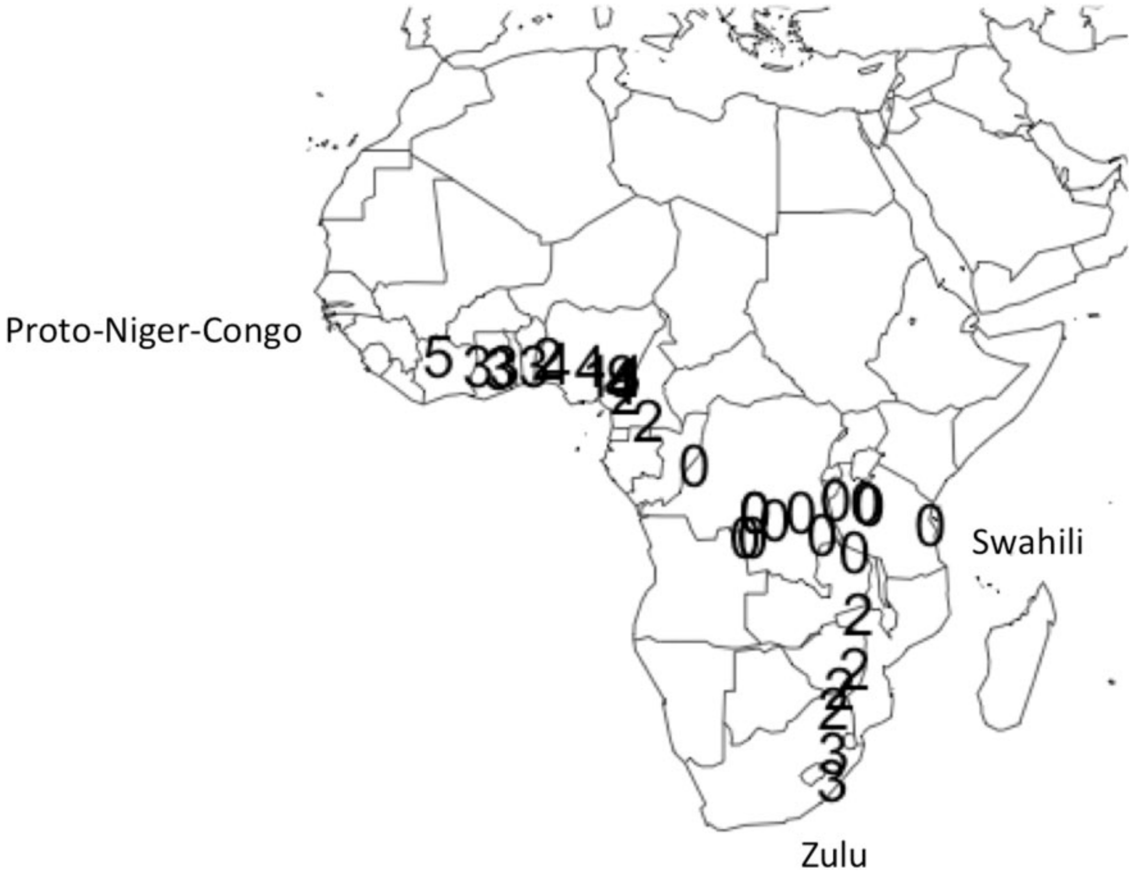

Figure 2. A plot of the migration of two Niger-Congo languages (Swahili and Zulu) from their Proto-Niger-Congo origin in west Africa, and the way that their number of tones have changed as they moved.

tone is associated with humidity within several different macro-areas, namely Africa, Eurasia, the Pacific, North America, and South America. They test the correlation between number of tones and humidity within areas; but continuing simply with the presence or absence of complex tone, using a logistic regression, complex tone turns out to correlate positively with humidity ($P < 0.05$) in three regions, Africa, Eurasia, and North America. How likely is it that these correlations will hold up within these regions purely by random evolution of tones and language contact? Continuing with simulations where the number of languages $N = 6$ (without phylogenetic weighting) and language contact spreads over $L = 100$ languages, there is a 47 per cent chance of holding within at least two macro-areas and a 15 per cent chance of holding within at least three. With a phylogenetic weighting, there is a 39 per cent chance of holding within at least two areas and a 11 per cent chance of holding within 3. Using a distance of 500 km rather than a fixed number of languages *L*, with $N = 6$ and 500 km, there is a 21 per cent of 2 and 3 per cent of 3. With $N = 10$ and 500 km, there is a 32 per cent of 2, and a 21 per cent of 3. With $N = 15$, there is a 37 per cent chance of 2 and a 10 per cent chance of 3.

In short, under these different models of language contact, it is quite unlikely that tone and humidity will correlate in three different macro-regions purely by chance, with that probability ranging between 3 per cent and 21 per cent depending on what assumptions are made in the simulations; but in general these probabilities are unexpectedly high, and moreover above the conventionally accepted significance level of 5 per cent.

3. The effect of language contact on creating correlations within families

Another finding of Everett et al.'s paper is that number of tones correlates within large language families, such as Sino-Tibetan (Pearson's $r = 0.16$, $P < 0.01$) and Niger-Congo (Pearson's $r = 0.3$, $P < 0.001$).

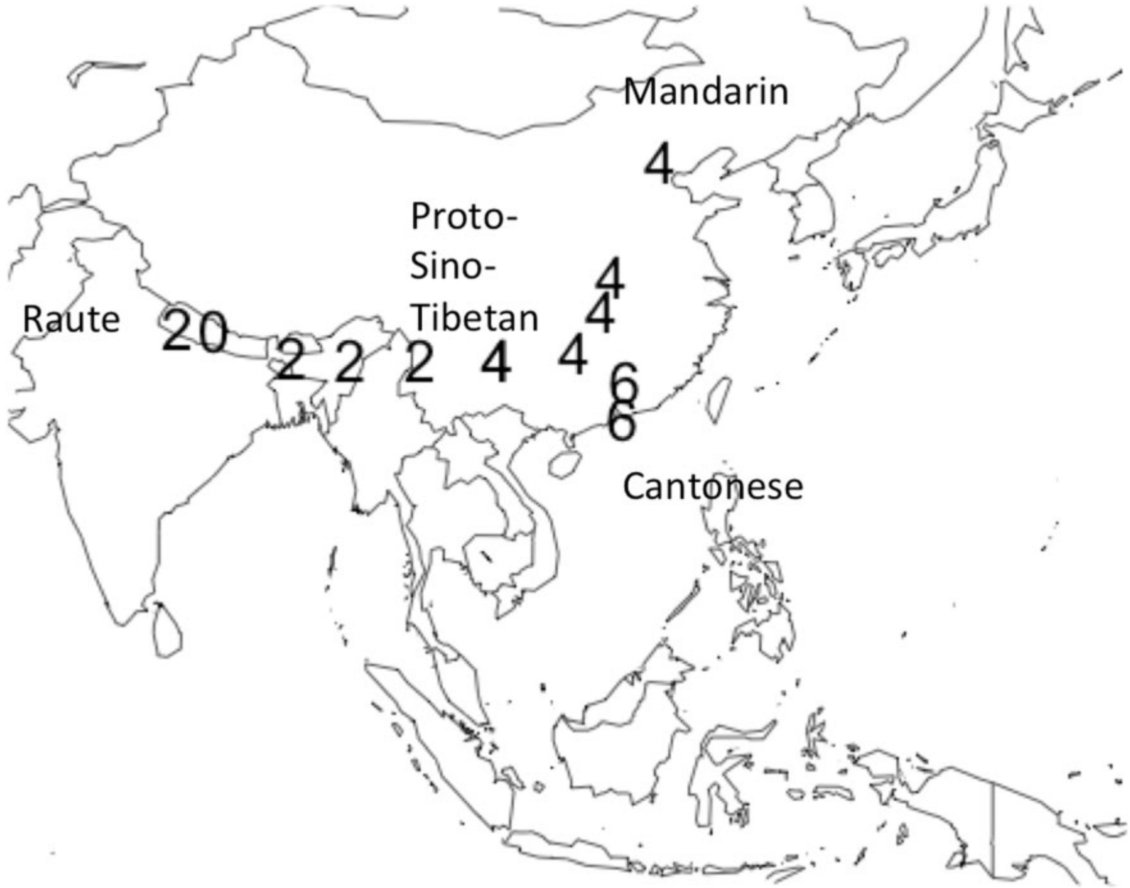

Figure 3. A plot of the migration of three Sino-Tibetan languages (Raute, Mandarin and Cantonese) from their Proto-Sino-Tibetan origin in west China, and the way that their number of tones have changed as they moved.

However, the major confound here is once again language contact. Sino-Tibetan languages also have fewer tones when they are near to generally nontonal Indo-European languages, and have more tones when near highly tonal Hmong-Mien languages. Niger-Congo languages similarly lose tones near nontonal (or low-tonal) families such as Nilo-Saharan and Afro-Asiatic.

In order to show this, I used maximum likelihood reconstruction of tones in Niger-Congo and Sino-Tibetan. I also used maximum likelihood reconstruction of location, treating longitude and latitude as a continuous variable that evolves by Brownian motion, in a basic form of phylogeography. The phylogenies of Sino-Tibetan were first taken from Glottolog (Hammarström et al. 2014), using uniform branch lengths, and then this was replicated using phylogenies based on neighbor-joining of languages using similarity between ASJP word lists (Wichmann et al. 2010, 2013). This methodology, while crude, gives reasonable results when reconstructing the locations of many language families (e.g. Austronesian is reconstructed to an origin in Taiwan and Bantu to Cameroon). The maximum likelihood reconstruction of ancestral number of tones and ancestral locations was done using the 'ace' function in the 'ape' phylogenetic package in R (Paradis et al. 2015).

An example of this is shown in Figure 2, which shows the path that two Niger-Congo languages (Zulu and Swahili) have historically taken through Africa and the way that their number of tones have changed while they were moving, according to one randomly selected reconstruction. Proto-Niger-Congo is reconstructed in this case to West Africa, and with five tones, then moving into Cameroon, then southward and eastwards. As this language moved through Africa, the number of tones began to decrease, going through a period of having no tones and then regaining tones as it moved into southern Africa. This is probably not wholly accurate (e.g. Narrow Bantu perhaps did not have zero tones, as is reconstructed here), but it represents what is most parsimoniously inferred from the modern distribution of numbers of tones in Niger-Congo.

When taking transition events in number of tones, the number of tones that languages transition to correlates with distance from Cameroon (Pearson's $r = 0.34$, $P < 0.001$), suggesting that these languages have tended to lose tones as they have been moving. What could cause this? It turns out that the number of tones that languages transition to correlates with humidity (Pearson's $r = 0.33$, $P < 0.001$). But another predictor of number of tones is which language families are nearby. The number of tones that Niger-Congo languages transition to correlates negatively with proximity to the nearest Nilo-Saharan language (Pearson's $r = -0.29$, $P < 0.001$), and similarly with proximity to the nearest Afro-Asiatic language (Pearson's $r = -0.23$, $P < 0.001$). A reasonable explanation for this would be that speakers of generally speakers of languages that are nontonal or with relatively few tones are simplifying the tonal systems of Niger-Congo languages. This is expected if there are interactions between these language families (whether by language shift or other kinds of bilingualism), because tones are hard for second-language speakers to acquire (Gottfried et al. 1997).

The short-term explanation for Niger-Congo languages losing tones as they moved southwards is therefore likely to be language contact rather than the change in humidity (or at least, this is a serious confound). The natural next question is why Nilo-Saharan languages and Afro-Asiatic languages are nontonal; could it be because they are found in dry areas? The answer is possibly just that it is due to chance; there is as much as a 47 per cent probability of complex tone being associated with humidity in at least two different macro-regions as shown in the previous section, and hence the fact that families such as Nilo-Saharan and Afro-Asiatic are nontonal does not in itself necessarily need an explanation.

Furthermore, in Sino-Tibetan, the number of tones that languages transition to does not in fact correlate with humidity (Pearson's $r = 0.06$, $P = 0.48$), in spite of the fact that there is a significant correlation without a phylogenetic control. There is a significant positive correlation however with proximity to the nearest Hmong-Mien language (Pearson's $r = 0.33$, $P < 0.001$) and a negative correlation with proximity to the nearest Indo-European language (Pearson's $r = -0.47$, $P < 0.001$). Hmong-Mien languages have the highest number of tones in Asia, suggesting that proximity to these languages caused some Sino-Tibetan languages to gain tones due to contact. Similarly, Indo-European languages generally have no tones or very few, suggesting that Sino-Tibetan languages have been losing tones near India due to simplification by contact with Indo-European. The path that three Sino-Tibetan languages (Raute, Mandarin, and Cantonese) took from a reconstructed location for Proto-Sino-Tibetan in western China is shown in Figure 3.

Language contact is therefore a much better predictor of the way that tone has evolved in Sino-Tibetan than humidity is, and in the case of Niger-Congo, it should be considered a serious confound.

4. Conclusion

The causal mechanism is intriguing and well worth testing in naturalistic contexts, such as in conversations in different Chinese varieties. However, language contact should be considered a serious confound in the way that it can create a positive global correlation between humidity and complex tone, including after controlling for language family, and even within specific macro-areas and language families. More generally, as Seán Roberts points out to me, a moral of these simulations is that correlational studies should take into account the geographical distribution of languages and even factors such as the shape of landmasses, as these provide unexpected confounds (such as the greater density of languages in humid places) to claims about how languages culturally evolve.

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Commentary: Defining and assessing constraints on linguistic forms

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1. The ecology of linguistic forms

In their paper, Everett et al. (2016) stress how a shift could or should take place from autonomous linguistic forms to ecologically adaptive ones. This raises the issue of the meaning of ecology when it comes to languages, and to what the Greek root of this word—*oikos*, the house or the habitat—actually refers.

Several authors have equated the ecology of languages with their social environment, i.e., communities of speakers. When describing the *ecology of language evolution*, Mufwene (2001) exemplified how situations of contact between several languages in colonial plantations resulted in specific selections and assemblages of linguistic forms. More recently, Lupyan and Dale's (2010) *ecolinguistic niche hypothesis* points at how differing social contexts may shape language structures, much as ecological niches shape organisms. They suggest in particular that a high percentage of adult L2 learners in a linguistic community may push toward less morphological complexity. Another example of social influences on linguistic forms is the debated positive correlation between the number of speakers of a language and the size of its phonological inventory (Hay and Bauer 2007; Bybee 2011).

The notion of ecology can also relate to the natural environment in which speakers live and interact, as it is the case in Everett et al.'s contribution. Different phenomena can be acknowledged, which may take place simultaneously or not in specific situations.

First, as highlighted by the authors, indirect influences may be identified: different ecological settings can induce different social or sociolinguistic situations, which may in turn partly shape linguistic forms. According to Nettle (1996), increased ecological risk leads to wider networks of mutual exchange and as a consequence reduced linguistic diversity and wider language areas. For Munroe et al. (1996), warm climates promote more frequent usage of Consonant–Vowel syllables and sonorous sounds, since they suit a predominantly outdoor life and distant communications. Intuitively, human migrations due to environmental changes may also result in language contact and change. In such cases, linguistic systems may undergo significant changes, but the causal impact of the environment may be said to be of *second order*.

Direct or *first-order* causation may take place on both sides of Saussure's linguistic sign. As for the *signified*, a language can exhibit adaptation or at least adequacy to the environment, among others in the way it may describe space with a geography-based system, offers a great diversity of lexical items to depict specific aspects of the environment, or yet uses spatial properties of the environment to express other conceptual domains such as time. For example, as detailed in Núñez et al. (2012), the Yupno speakers of Papua New Guinea Highlands see the past as downhill and the future as uphill, something that would be very unlikely for populations living in much flatter surroundings. Turning to the *signifier*, i.e. the linguistic signals, Shannon's sender, receiver, and channel of communication (Shannon 1948) may be summoned, since adaptation to the environment may relate to them distinctly. Everett et al.'s study of the effect of aridity on vocal folds points primarily to the emission of messages, and how a linguistic system may respond to perturbation