EXPLORING POTENTIAL CLIMATIC EFFECTS ON THE EVOLUTION OF HUMAN SOUND SYSTEMS

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ABSTRACT

We suggest that it is now possible to conduct research on a topic which might be called *evolutionary geophonetics*. The main question is how the climate influences the evolution of language. This involves biological adaptations to the climate that may affect biases in production and perception; cultural evolutionary adaptations of the sounds of a language to climatic conditions; and influences of the climate on language diversity and contact. We discuss these ideas with special reference to a recent hypothesis that lexical tone is not adaptive in dry climates [17].

Keywords: Phonetics, climate, cultural evolution, adaptation.

1. INTRODUCTION

In theory, there are three ways in which climate could affect language. First, linguistic articulators may be biologically adapted to aspects of climate. These adaptations could shape the possible space of language sounds. Secondly, the climate can affect aspects of production and perception which may cause aspects of language to adapt via cultural evolution. For example, the vocal folds are affected by the inhalation of dry air in a way that affects phonation. Also, in spoken languages, the air is the interface between production and perception, and so a possible source of noise or bias in cultural transmission. Finally, the climate may have indirect affects on cultural evolution by influencing population migration and contact which could drive innovation and divergence.

The main focus of evolutionary linguistics has been to identify universal properties of languages and link them to conditions of genetics or culture that humans have in common. However, some studies have also considered how idiosyncratic aspects of a linguistic community might affect the development of its language, such as differences in demography [4,23] or genetic biases [6,10]. In a similar way, we suggest that it is possible to research the differences in language based on climatic differences. In this paper we delineate the three ways in which climate could possibly impact the evolution of language. We sketch out the various questions and problems of such a line of research, and offer a clear methodological path for this line of research to be pursued constructively. As a case study, we use our recent study of the idea that the inhalation of dry air makes the precise control of tone difficult, leading, via cultural evolution, to fewer languages using lexical tone in dry environments [17].

2. POTENTIAL EFFECTS

2.1. Climate and biological evolution

Many animal communication systems show adaptation to the environments in which they are used. Animal signals adapt to environmental noise and obstructions to signals such as plant cover (e.g. [28]; see [39]; though see [5]), and some studies have found these factors to be better determiners of song properties than climate [21]. However, temperature and humidity also affect acoustic absorption [3], meaning that dry, warm environments have greater absorption of high frequencies. Bird and bat signals adapt to higher absorption climates by using narrower bandwidth signals that carry further in these conditions, with bats adapting within climates over seasons as well as between climates [34] (though songs are learned to some extent, so there may be gene-culture co-evolution).

Insect chemical signals are also adapted to humidity and temperature, which affect evaporation and diffusion rates [1].

Biological adaptations to the climate may also have knock-on effects for language. For example, the morphology of the nasal cavity has evolved in different human populations so that those in drier, colder climates are higher and narrower which increases the contact between air and nasal wall, helping to humidify the inhaled air [30]. These adaptations could have small effects on nasal sounds used in speech production [16]. Interestingly, recent work has also demonstrated altitude-based effects of the formants associated with nasal phonemes [31].

More generally, we also note that long-term, pre-historic changes to climate have been linked with more general adaptations such as bipedalism, which may have allowed larger human group size [22]. Both of these aspects have been suggested as pre-adaptations for language [22,40], suggesting a link between differences in climate and differences between species.

2.2. Climate and cultural evolution

The basic principle behind studies of cultural evolution is that a selective pressure on communication can transform the structures of a language over time. Based on a similar line of argument to the ecological adaptiveness of animal signalling, [19] suggest that sonorous speech sounds are better at carrying longer distances, and so would be more adaptive in environments where plant cover was dense, and hence warmer climates (see [8] for a direct test of plant coverage using spatial regression). This combines with assumptions about aspects of culture such as communities in warmer climates spending more time outdoors and therefore also communicate over relatively large distances. This theory does not involve a direct influence on the climate on as in [17], but rather an interaction between the climate, the ecological environment and interactional norms that bring about a selective pressure (see also [15]).

Perhaps one of the reasons that the climate has not been more widely considered as a selective pressure on languages is the focus on language learning as the locus of language change. Acquisition has been conceptualised by some as primarily a cognitive task, and there is no theory that would predict substantial differences in formal learning systems nor neural functioning based on climate. However, if we see the locus of language change as the production and perception of individual utterances [9], then the interface between the physical articulators and the medium of communication (the air) becomes more salient.

Another reason that the influence of climate might be doubted is the known role of social factors on language change. Languages die, survive or change based on historical events, power, politics and socioeconomic factors. Given that the effect of climate on language should be subtle (it's certainly not impossible to speak a tone language in dry air) and take a long time to propagate, it's possible that these effects could be masked by the more powerful social forces. However, this is an empirical question, and large-scale cross-linguistic databases make it feasible to detect subtle influences.

2.3. Climate and diversity

There has also been some implication of indirect influence of the climate on linguistic diversity. Essentially, the climate can affect the 'carrying capacity' of the environment, affecting demographics of speakers. Nettle [29] argues that certain climates and ecologies foster certain kinds of social interaction between linguistic groups. A high carrying capacity leads to demand for material wealth, so linguistic groups invest in each other through learning each others' languages, causing linguistic diversity to be an asset. Nettle finds correlations between linguistic diversity and climatic factors such as temperature and mean growing season.

Linguistic change is also brought about through migration (leading to isolation) and contact. The climate can influence migration patterns (e.g. extreme changes in climate can force groups to move) or influence where contact is likely to happen. [20] estimate the timing of divergence of languages in the Uralic family using Bayesian phylogenetic techniques, and compare this to the changes in climate. They argue that changes in climate align with linguistic divergence. One suggested explanation is that a rise in temperature leads to a rise in population size [36], which makes migration more likely (though see [32] for an argument that innovation drives migration). Similarly, a decrease in temperature can decrease the population, leading to conservatism.

2.4. Interactions between climate, biology and language

Aspects of climate, biological evolution and culture may not be independent from one another. For example, an adverse affect of climate on phonation may be adapted to biologically (e.g. increasing saliva production, a longer, narrower nasal cavity in response to drier air) or culturally (e.g. the cultural practices of breathing in particular ways to avoid desiccation of the mouth and larynx). This may cause two problems. First, climatic differences may be neutralised by biological adaptations, meaning that there is no difference in the effect of climate on production. Secondly, variation in genetics or morphology could mean that climate may not affect production in the same way in all populations. Controlling for this is difficult, but one solution is to gather cross-cultural data, combining knowledge from geography, genetics, linguistics and anthropology.

3. DEMONSTRATING CAUSAL EFFECTS

A study in evolutionary geophonetics, focussing on cultural evolution, would ideally proceed in the following way. First, evidence is obtained that a change in a certain property of the climate causes a change in production or perception. For example, evidence that a property of climate affects the articulators of language that leads to a difference in production, such as the inhalation of dry air causing changes to the vibration of the vocal folds that affect acoustic properties of phonation. This is not always straightforward, since measurements can involve invasive methods (cf. [25]). Alternatively, an effect could be demonstrated on perceptual systems (e.g. hearing being affected by temperature or humidity, [27]) or on the way sound is carried in different climates [2]. We also note that similar predictions can be made for languages in other mediums, for instance [33] discusses the impact of temperature on sign language in the Arctic.

Crucially, one must be able to demonstrate that the effects on one aspect of interaction lead to differences in the other, for example that the changes in phonation caused by dry air lead to differences in perception. Usually, this difference will involve a difference in a specific aspect of production, rather than an effect across the board (which may make predictions more difficult).

Once a physical link is proposed, a prediction can be made about the way in which languages will change in different climatic environments. This involves a prediction of how individual interactions will be affected, and also how those interactions will accumulate into wider change. In general, the prediction will be based on cultural evolutionary principles: the climate provides a selective pressure which causes differential rates of successful production and perception for particular linguistic aspects. Predictions may not be straightforward to make, and may involve computational models of both articulation (e.g. [26]) and cultural evolution (e.g. [35]). This leads to a concrete prediction of how a given property of language will co vary with a property of the environment.

This can then be tested in several ways. A synchronic pattern can be identified in current languages. This is not straightforward either due to the non-independence of languages and other statistical concerns. However, it provides evidence that the current state of linguistic distributions is compatible with the prediction

Diachronic evidence is also obtainable. This could be done by a case-study of the divergence of two languages with the expected differences. More large-scale studies are also possible by reconstructing linguistic and climatic history. Linguistic history can be estimated from current data using phylogenetic techniques [14]. Similarly, climatic history can be reconstructed from current sources such as sediment or pollen. One can then test whether a change in the environment coincides with the predicted change in the linguistic property.

We also note that the general principle of linguistic change due to climatic influence could be demonstrated through experimental techniques such as iterated communication games [37]. Such techniques may, in and of themselves, be used to demonstrate reasonable causal interpretations of the associated distributional data.

Following these steps, one may arrive at a demonstration of a causal link between climate and language. However, we note that not all studies are immediately possible, and some unfeasible without considerable effort. Different kinds of evidence can be collated piecemeal to provide a robust argument.

3.1. A case study: Tone and Humidity

[17] review the literature on the effects of inhaling dry air on the larynx and vocal folds. Dry vocal folds increase phonation threshold pressure and perceived phonation effort, and create a signal with higher rates of jitter and shimmer. In short, dry vocal folds make it harder to precisely control pitch (though there is not yet direct evidence that it influences production in a perceivable way). This is a more direct link between climate and language than suggested by previous studies.

All languages use pitch contrasts for various purposes, often pragmatic. Also, tonal contrasts are often not simply pitch-based but rely on other factors such as laryngealization. Additionally, F0 modulation can be as extreme in non-tonal languages as in tonal ones. However, it is still reasonable to assume that tonal languages, particularly those with complex tone, require that a generally higher burden be placed on the maintenance of precise pitch patterns in order to contrast meaning (we note that this may also be empirically testable).

Assuming that this puts a selective pressure on individual utterances, which is amplified by cultural evolution, leads to a prediction that languages in dry areas will not use lexical tone. While humidity is predicted to affect phonetic production, rather than phonology, we predict that, over time, biases in phonetic production affect changes to the phonological system.

[17] use a database of over 3,700 languages [11] to demonstrate a synchronic pattern: languages with complex lexical tone are rarer in areas of the world

with dry climates, and that this distributional tendency is not simply owed to genealogical or contact-based confounds.

The analysis was complicated by two factors. First, the languages were related historically, meaning that they did not constitute independent samples. Secondly, the prediction is a uni-directional implication: it suggests that complex tone should be rarer in cold climates, but makes no prediction about the distribution in warm climates. In this case, typical regression frameworks, which are suited to bi-directional implications, are not appropriate.

The solution was to use a Monte Carlo framework. Random samples of languages with complex and non-complex tones were taken and the distribution of humidity in each sample was compared. It was predicted that the distribution for complex tone languages would have a higher lower-quartile (more humid) than the non-complex languages (the mean of the two distributions could be similar at the same time as there being a 'gap' in the complex tone languages). This provided a direct way to test the prediction of a difference in low-humidity languages. The samples were balanced by selecting only one language from each language family, and by having the same number of languages in both the complex and non-complex samples. This addressed the first problem.

The study engendered discussion in various quarters, and attracted some scepticism. Some of this scepticism was, we suspect, the unfortunate byproduct of media reports suggesting e.g. a simple correlation between humidity and tonality—a position not propounded in our paper. Additionally, some of the scepticism resulted partly from the unfamiliar statistical methods used, and partly from the unusual claim that different languages may be subject to different evolutionary pressures rather than the more traditional bias towards studying effects that apply universally to speakers (e.g. processing, memory). There were also questions about why the effect should be seen specifically for lexical tone. We stress, however, that the link between humidity and lexical tone does not exclude the potential effects of humidity on other uses of pitch in language, such as clausal prosodic contours. Future work might explore this, but it is worth noting that the transmission or borrowing of lexical pitch and clausal pitch likely work quite differently. Criticisms of the suitability of the data on tone were more perspicacious. However, extant databases only allow us to test our hypothesis as it relates to major tonemic categories across languages. It is worth underscoring as well that, subsequent to the publication of our paper, no alternate hypotheses have been presented that explain the climatic-tonemic association we have uncovered. We emphasise that the hypothesis derives from an *a priori* prediction from known physical causes, and that it can be quantitatively tested.

It isn't yet known whether the link between tone and climate is truly supported by historical change, though the intra-family analyses offered in [17] do suggest that in four of the world's major language phyla historical patterns are congruent with the suggested causal effect. The expectation is that languages moving into dry areas will be less likely to gain tone contrasts in the first place, rather than dry air leading to loss of tone or humid air leading to the adoption of tone.

4. DISCUSSION

4.1. Implications for language change

Many studies of cultural evolution focus on cognitive selective pressures (e.g. processing, memory, frequency etc.), which are usually assumed to apply universally. The results in [17] suggest that some pressures may not be universal, but only apply in particular situations, for example in very dry contexts that influence vocal-tract physiology in particular ways. This adds to the literature on niche-specific cultural evolution, such as the effect of population size on morphological complexity, or demography on phoneme inventory.

4.2. Implications for language acquisition

An interesting question is whether the interaction between climate and production and perception will also affect acquisition, either learning a native language (e.g. from birth, L1 acquisition) or learning a language later in life (L2 acquisition).

With regards to L1 acquisition, difficulty in producing or perceiving sounds could lead to biased acquisition. Since languages must adapt to be learnable by children [7], this could also lead to language change. While [17] does not address this issue for tone, and while there is some evidence that pitch is an important cue in learning [18], we think this is not very likely. Children have differences in production due to developing articulators whose effects are likely to be much greater than those of climate, and which disappear with maturity. This hypothesis is also very difficult to test, given that a change in climate almost always brings with it a change in social factors, cultural contexts and linguistic phenomena that influence learning.

However, the case might be different for L2 acquisition. Adults find learning the phonetics and phonology of a new language challenging. L2 learning is also sensitive to psychological aspects such as confidence and motivation (e.g. [12]). So if sounds are harder to produce or perceive due to dry air, adult learners may find them harder to learn. In theory, this is testable by looking at learning performance over a range of climates. However, again, with a difference in climate comes a difference in culture, socioeconomic status, motivation and so on, which would complicate the answer.

4.3. Implications for linguistic typology

Theoretically, there are many other aspects of the sounds of a language that could be affected. Also, the sounds of a language can, in principle, have a knock-on effect on other parts of language like morphology or syntax. For example, [38] discuss the idea that lexical tone and phrase-level intonation compete for the same linguistic resource (pitch), and show that languages with lexical tone are more likely to develop additional grammatical means of distinguishing questions versus statements.

Other implications might be made for the semantics of temperature [23] and possible extensions into metaphor, but are not discussed here.

4.4. Implications for other aspects of culture

The general hypothesis offered in [17] might predict differences in music or singing styles. However, there are differences in the function between singing and language. Singing is often performative, while language is communicative. In this case, there may be less pressure on singing to adapt to the environment. In fact, performative pressures may act in opposition to pressures for simplicity and efficiency.

5. CONCLUSION

When we look at the world's languages, we see a lot of variation. Some aspects, like lexical tone, can seem completely alien to speakers of many European languages. Similarly, the variable stress patterns of languages like English can seem strange to speakers of other languages. However, rather than seeing these differences between languages as odd or due to chance, we suggest that languages are well adapted to the communicative needs of its speakers. In some cases, this can also mean adaptation to climate. Using the recent findings in [17], we have sketched out an initial heuristic approach to a nascent field of inquiry, one we have termed evolutionary geophonetics.

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