GENE-CULTURE COEVOLUTION OF A LINGUISTIC SYSTEM IN TWO MODALITIES

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Complex communication can take place in a range of modalities such as auditory, visual, and tactile modalities. In a very general way, the modality that individuals use is constrained by their biological biases (humans cannot use magnetic fields directly to communicate to each other). The majority of natural languages have a large audible component. However, since humans can learn sign languages just as easily, it's not clear to what extent the prevalence of spoken languages is due to biological biases, the social environment or cultural inheritance. This paper suggests that we can explore the relative contribution of these factors by modelling the spontaneous emergence of sign languages that are shared by the deaf and hearing members of relatively isolated communities. Such shared signing communities have arisen in enclaves around the world and may provide useful insights by demonstrating how languages evolve as the deaf proportion of its members has strong biases towards the visual language modality. In this paper we describe a model of cultural evolution in two modalities, combining aspects that are thought to impact the emergence of sign languages in a more general evolutionary framework. The model can be used to explore hypotheses about how sign languages emerge.

One of the great linguistic discoveries of the 20th century has been that our linguistic abilities are, to an extent, independent of the natural language mode through which it is expressed and understood. That is to say, sign languages parallel spoken languages in terms of the areas of the brain that are involved in production and processing, in the patterns of language acquisition, as well as the degree of grammatical diversity among them (Meier, Cormier, & Quinto-Pozos, 2002). Sign languages may emerge spontaneously in at least two types of settings. Urban sign languages often emergence in response to the congregation of deaf individuals at government institutions for the deaf, as for instance in the well-documented case of Nicaraguan Sign Language (Senghas & Coppola, 2001). Alternatively, sign languages may arise in communities with an exceptionally high incidence of (often hereditary) deafness (Zeshan & de Vos, 2012). In the latter type of setting the sign language is used by both deaf and hearing community members, engendering a high degree of social integration for deaf individuals. Such so-called shared signing communities may therefore provide unique insights into the rel-

ative contribution of biological, cultural, and social biases in the emergence of signed languages.

However, the cases of signing communities documented so far show a striking diversity in their social attitudes to deafness, demography, history, ecology and the proportion of hearing L2 speakers (Zeshan & de Vos, 2012). There are also structural differences between the languages, such as differences in phonology or spatial grammar, possibly due to different amounts of cross-modal contact. The diversity makes it difficult to make generalisations about how these factors affect the emergence of a signing community. For example, the critical mass of deaf people that is needed for a shared signing community to emerge is not known. Models can help researches think about these questions.

1. Model

We use a model adapted from Burkett and Griffiths (2010) and Smith and Thompson (2012) which simulates gene-culture co-evolution in an iterated learning framework (for a full description, see Roberts, Thompson, & Smith, 2013). Individuals are modelled as Bayesian agents who must decide what proportion of each modality to use in communication, given their prior bias and their observations of the behaviour of other agents. Since hearing communities tend to have an audible linguistic system as an important part of their communication, hearing agents have a bias favouring the auditory modality. It is obviously a weak bias, because both hearing and deaf learners can learn non-audible (signed) languages. It is also well-documented that speakers generally distribute the message over both auditive and visual forms (Enfield, 2009; Kendon, 2004). At any rate, deaf learners can be characterised as having a very strong bias towards the visual modality (learning an audible language is hard).

The agents reproduce biologically, according to a fitness function that gives a higher probability of reproduction to individuals who can socialise successfully through language. The prior bias is inherited biologically (with some chance of mutation). This means that offspring of deaf individuals will inherit the bias against audible languages (deafness is hereditary).

We can use this model to explore the emergence of deaf communities within hearing communities, or to model the competition between auditory and visual modalities. In a community of deaf individuals, we would expect a mainly non-audible language to emerge. However, what happens in a community with mixed biases where modalities might be in competition?

Since the dynamics of this kind of model are not well understood analytically, we obtain results by numerical simulation. We run the model with hearing individuals until it converges (around 200 generations). At this point, deaf individuals are introduced into the simulation who have a strong bias against learning an audible language. We can then observe how the community changes, both in terms of the number of deaf individuals, and the use of each modality. Since deaf individuals

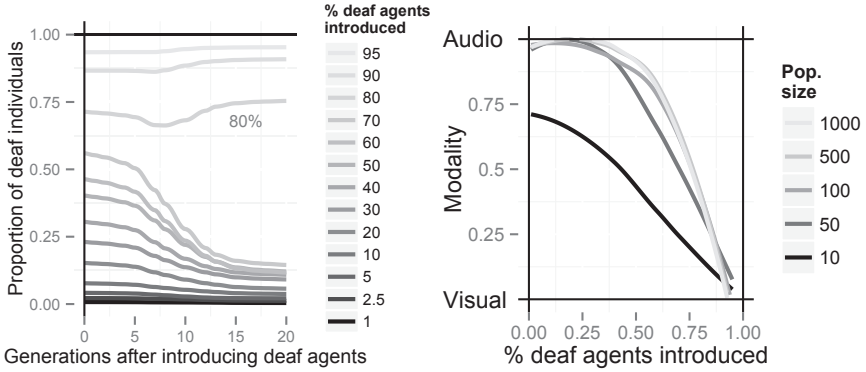

Figure 1. **Left:** Deaf individuals are introduced into a hearing population 200 generations after initialisation. The graph shows how the proportion of deaf individuals changes over generations depending on the initial number of deaf individuals introduced (lines are LOESS fits of 10 independent runs). Between 70% and 80% of the population needs to be deaf for deaf individuals to remain stable or increase. **Right:** The average modality used in a population for different population sizes, under the standard fitness function. Means are taken from 8 generations after introducing deaf individuals. Larger populations require a greater proportion of deaf individuals to affect the overall modality.

essentially cannot learn an audible language, the two aspects will be correlated. However, we also show that this is not always the case.

1.1. *Results*

The results demonstrate that in a wide range of scenarios, communities of hearing individuals using primarily audible communication are resistant to deaf individuals (see figure 1a). Shared-sign languages are unlikely to survive except when the initial proportion of deaf individuals introduced into the community is very high. The weak bias for audible languages is amplified over generations of cultural transmission so that the majority of the communication system is audible. The average modality of communication used by the population reflects the number of deaf individuals, with a large number of deaf individuals required to change the modality of the population (see figure 1b). However, in very small populations, a smaller proportion of deaf individuals may influence the modality of the language in the short-term (up to 10 generations).

These results suggest that a monolingual signing community is unlikely to emerge. However, there are conditions under which a bimodal-bilingual shared-signing community can emerge and where deaf individuals can thrive. If the ability to communicate in both modalities is prestigious within a society, then a communication system that uses both visual and auditory modalities will emerge. This is independent of the community having deaf individuals (although the presence

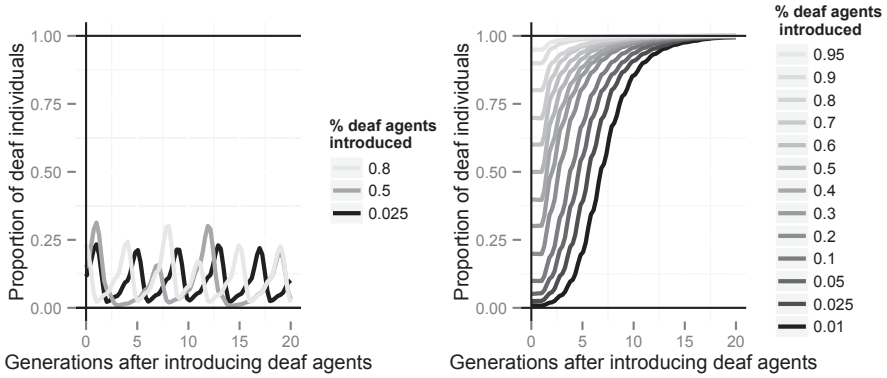

Figure 2. **Left:** Results from the model where there is a social prescription against marriage between deaf individuals. The population size matches that of the Kata Kolok community. **Right:** Results from the model using the 'parity' fitness function and a structured population of the same size as the Kata Kolok community (2189). Even very small numbers of deaf individuals introduced into the model will increase within a few generations.

of deaf individuals is an obvious motivation for the prestige of a multi-modal ability).

The social structure of the community also makes a difference. In stratified communities where agents' fitness is only derived from the communicative success between a few nearest neighbours, the community maintains a non-audible component in the language for longer. This happens because small 'enclaves' of deaf individuals can be maintained, where using a non-audible language leads to good communicative success and high probability of reproduction.

The dynamics of social interaction make a difference, too. Communities with deaf individuals are sustainable when linguistic differences lead to higher fitness (figure 2a). This can happen, for instance, if linguistic differences are perceived as resources rather than limitations (as is the case in some sign language communities). In this case, the linguistic system of the community as a whole utilises both modalities equally. The number of deaf individuals oscillates with a phase determined by the initial number of deaf individuals introduced.

Finally, if the fitness function is neutral with regards to the modality of communication (the 'parity' function, where reproduction is linked to the ability to communicate effectively, regardless of modality), the proportion of deaf individuals and non-audible language increases in small, structured societies. In fact, in this social set-up, the modality of communication is predominantly visual and the community is resistant to hearing individuals (see figure 2b). This happens because deaf select the same proportion of each modality (all visual), and so maximise their communicative fitness with other deaf individuals. Hearing individuals

are more likely to select a range of proportions of each modality, meaning that they have weaker fitness.

2. Conclusion

The extent to which modalities are exploited in communication systems depends on genetic constraints, cultural transmission and social factors. We demonstrated that the links between learning biases, modality, communicative success and the social perception of language can be complex. We hope this model can help frame the exploration of demographic differences between different types of sign languages. Future improvements could include more realistic genetic inheritance and social structures. We also hope that this paper demonstrates the relevance of shared sign languages for language evolution: given their relatively limited time depths and relative isolation, the diffusion of structural features within these communities could be charted to track their historical development.

References

Burkett, D., & Griffiths, T. (2010). Iterated learning of multiple languages from multiple teachers. In A. Smith, M. Schouwstra, B. de Boer, & K. Smith (Eds.), *The evolution of language: Proceedings of EvoLang 2010* (p. 58-65). World Scientific.

Enfield, N. J. (2009). *The anatomy of meaning: Speech, gesture, and composite utterances.* Cambridge University Press.

Kendon, A. (2004). *Gesture: Visible action as utterance.* Cambridge University Press.

Meier, R. P., Cormier, K., & Quinto-Pozos, D. (2002). *Modality and structure in signed and spoken languages.* Cambridge University Press.

Roberts, S., Thompson, B., & Smith, K. (2013). Social interaction influences the evolution of cognitive biases for language. In E. Cartmill, H. Lyn, H. Cornish, & S. Roberts (Eds.), *The Evolution of Language: Proceedings of the 10th International Conference (EVOLANG10).* World Scientific.

Senghas, A., & Coppola, M. (2001). Children creating language: How Nicaraguan Sign Language acquired a spatial grammar. *Psychological Science*, *12*(4), 323–328.

Smith, K., & Thompson, B. (2012). Iterated learning in populations: Learning and evolving expectations about linguistic homogeneity. In T. C. Scott-Phillips, M. Tamariz, E. A. Cartmill, & J. R. Hurford (Eds.), *The Evolution of Language: Proceedings of the 9th International Conference (EVOLANG9)* (p. 227-233). World Scientific.

Zeshan, U., & de Vos, C. (Eds.). (2012). *Sign languages in village communities: anthropological and linguistic insights.* Berlin: Mouton de Gruyter.