DID POST-NEOLITHIC CHANGES IN BITE CONFIGURATION IMPACT SPEECH? A NEW APPROACH TO THE QUESTION

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Blasi et al. (2019) offer evidence that post-neolithic changes in bite configuration, owed to the adoption of agriculture, have led to the innovation and proliferation of labiodental consonants in the world's languages. Here we investigate the putative association between agriculture and labiodental consonants via a new approach that does not rely on phoneme inventories. Given that labiodentals are apparently characterized by reduced muscular effort in populations with agriculture-influenced bite configurations, we test whether labiodental sounds are actually more prevalent in languages whose speakers rely on agriculture. We rely on word lists from the Automated Similarity Judgement Program (Wichmann et al. 2018), which contains transcribed lists of common words in thousands of languages. We analyze the relative frequency of sound types in the word lists of agricultural and hunter-gatherer populations, respectively, finding differing mean rates of labiodental usage in populations with distinct subsistence strategies. Using a linear mixed-effects model to control for relatedness and contact, we find support for an association between the frequency of labiodental consonants and the use of agriculture.

1. Introduction

Do minor cross-population variations in vocal tract anatomy foster disparities in the sound systems used in languages? The "uniformitarian hypothesis" prevalent in linguistics maintains that languages evolve in ways that are not significantly impacted by such variations, yet this hypothesis has been called into question by recent research on several sound types. (Dediu & Moisik 2019, Dediu, Janssen, & Moisik 2019, *inter alia*) Most prominently, perhaps, Blasi et al. (2019) suggest that post-neolithic changes in the bite configurations of agricultural populations have yielded effects on the phoneme inventories of the world's languages: Labiodental consonants are now relatively common in the world's languages, putatively due to the reduction of bite-to-bite configurations and the increase in overjet and overbite owed to the softer foods characterizing agricultural diets.

Blasi et al. support this intriguing hypothesis, first suggested by Hockett (1985), with a series of findings. Perhaps most crucially, those findings include a worldwide association between labiodental consonants and agriculture judging from the roughly 2,000 cultures considered. This association is crucial to the hypothesis under question since, were it absent we would have little evidence to believe that the modeled reduced muscular effort, characterizing labiodentals in mouths with overbite and overjet (when contrasted to "flat" bites), is sufficient to meaningfully impact speech. After all, it is known that there are minor cross-population differences in vocal-tract anatomy. The question is whether such differences are actually sufficient to have any meaningful effect on speech. While Blasi et al. (2019) offer compelling diachronic evidence for their case, such historical evidence is based primarily on Indo-European languages. In short, the worldwide distribution of labiodental sounds is essential to illuminating this issue. Here we investigate this distribution with a new and complementary method. We aim to contribute not just to the specific hypothesis promoted by Blasi et al. (2019), but also to the larger question of whether extra-linguistic factors influence the ways that languages evolve by creating selective pressures for/against some features. Such factors have been suggested in other recent work. (e.g. Everett 2017)

2. New approach

Blasi et al. (2019:6) suggest that "labiodental production effort" is reduced, by about 30% in fact, in populations without the edge-to-edge bite configuration that is characteristic of hunter-gatherer groups. Given that articulatory effort is at the heart of the tested hypothesis, one could argue that the phoneme data on which Blasi et al. rely offer an essential but still incomplete depiction of the relevant typological data. If the trend towards the inclusion of labiodental sounds in a language is (partially) the byproduct of articulatory ease and production-effort reduction, then we might expect that speakers with edge-to-edge bite generally rely on labiodental sounds less in speech. Conversely, we might expect that speakers with overbite and overjet rely on such sounds more in speech. Arguably, phonemic status is a proxy for what we are ultimately interested in, viz. the rate of occurrence of labiodental sounds in the speech stream. Consider the following points, which underscore the need for examining the rates of occurrence of a sound as opposed to only examining its binary phonemic status in a language: A language may have a given phoneme, but that phoneme may be rare in speech—perhaps contrastive in only a few minimal pairs. If a "rare" labiodental phoneme exists in the language of a group of agriculturalists, this case would support Hockett's hypothesis under a phoneme-based analysis. But it would arguably not

support the hypothesis nearly as well as a case in which a labiodental phoneme was frequent in the speech of a culture of agriculturalists. The converse possibility also underscores the desirability of the approach we pursue below: Suppose a language of hunter gatherers has no labiodental phonemes, but labiodentals do occur in speech as allophones of some related phoneme. For example, perhaps a phonemic bilabial stop is lenited word-finally. Such a scenario would be considered consistent with the hypothesis under Blasi et al.'s analysis, but would be dissatisfying from the perspective of sound usage. After all, the phonetic realization of a sound is what actually requires muscular effort, and the reduction of muscular effort can only be realized in phonetic patterns. While the biomechanical modeling in Blasi et al. (2019) clearly suggests that labiodental consonants require less production effort in populations without edge-to-edge bite, to test whether this reduction actually impacts speech significantly we should also consider how phonemes are reified phonetically. To be clear, we are not arguing against the phonemic approach utilized in Blasi et al. (2019), and in fact the consideration of phoneme inventories is also critical, particularly as it sheds light on the diachronic claim central to Hockett's original hypothesis. Yet the rate of occurrence of relevant phonetic units in speech is, in our estimation, another factor to consider in testing the hypothesis.

The suggestion that all phonemes do not equitably represent phonetic patterns in speech is supportable with specific examples. Consider, for instance, the voiced postalveolar fricative (/ʒ/). This sound is phonemic in English but only because of a few minimal pairs (e.g. "beige" [beʲʒ] vs. "base" [beʲs]). Recent analysis of the frequency of English phonemes has found that this consonant represents about 0.2% of sounds in large corpora of speech. The most common consonantal phoneme in those same data, /n/, represents about 13% of all sounds. So one consonantal phoneme is about 63 times as common as the other, meaning they are not equally representative of phonetic patterns in a language. (Chin et al. 2012) A recent meta-analysis of studies on 32 languages' sound systems observed that a sound's frequency in phoneme inventories across languages is not always a good indicator of its frequency in actual speech within languages. (Gordon 2016) Some sounds are less frequent in speech than we might expect given their commonality in phoneme inventories. This was found to be true with respect to the voiceless labiodental fricative /f/, the most common sort of labiodental phoneme. (Gordon 2016)

3. Methods & Results

We examined the largest database of phonetically transcribed word lists, the Automated Similarity Judgment Program. This database contains between 40-100 words for each of about 7000 language varieties. This lends typological breadth to our approach, though with clearly limited depth. This limitation is being addressed in follow-up work with other data sources, though it should be noted that the 40-100 common words in the ASJP data are generally frequent in speech and are often reasonable indicators of more pervasive sound patterns in the represented languages. (Everett 2018) The languages in the ASJP database were cross-referenced with the same subsistence database used by Blasi et al. (2019) (derived from Güldemann et al. (2019)), allowing us to rely on the same principal subsistence categorization of languages/cultures. This approach yielded 2756 data points for which word list data could be contrasted with the subsistence-strategy data. For each of the associated 2756 word lists, the total number of labiodental tokens was tabulated. This total was then divided by the entire number of consonant tokens, for each word list (vowels and non-segmental symbols were ignored). This yielded a "labiodental ratio" value for each of the word lists. We relied on a function written by CE via the *stringr* package in *R*. We also used a function written by SC with MATLAB, and then contrasted the results of SC's approach and CE's approach to ensure that the labiodental ratios obtained were identical. (Data and code available upon request.) The labiodental ratio is the proportion of all consonant segments in a word list that are [f] or [v], as all labiodental sounds in the ASJP data are coded with [f] or [v]. Other labiodental sounds exist but are much rarer. Still, it must be acknowledged that the phonetic transcriptions in the ASJP database are sometimes coarse. Yet the typological breadth they offer creates clear advantages as well.

At the roughest level of analysis, prior to instituting any controls for Galton's problem, Hockett's hypothesis is supported by our approach. As is evident in Figure 1, the dialects of hunter gatherer populations skew towards the lower end of labiodental usage. In Table 1 the mean labiodental ratios of word lists are provided, categorized according to the subsistence strategy associated with the speakers of the dialects represented in the lists. For the 2223 dialects categorized as belonging to non-hunter-gatherers by Güldemann et al. (2019), the proportion of consonantal phonetic segments represented by labiodental consonants averages about 2.2%. In contrast, for the 533 word lists categorized as belonging to hunter-gatherers, the proportion of labiodental consonants is about 0.77%. In other

words, labiodental consonants are almost three times as common in languages in agricultural groups, across all word lists in the data.

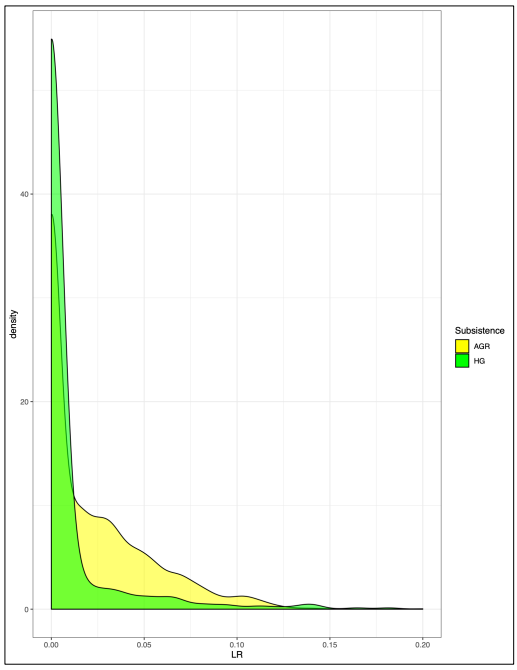

Figure 1. Density distribution of "labiodental ratios", categorized according to subsistence strategy most associated with a dialect's speakers.

Table 1. Proportion of all consonants in phonetically transcribed word lists that are labiodental.

	mean	s.d.
Non-hunter-gatherer (N=2223)	0.0217	0.029
Hunter-gatherer (N=533)	0.0077	0.024

The values in Figure 1 and Table 1 could be distorted by a few language families or linguistic regions, making their interpretation difficult. In Figure 2 the geographic distribution of the top quartile of languages, in terms of prevalence of labiodental consonants, is plotted. These dialects are not randomly distributed geographically. For instance, labiodental consonants are quite prevalent in Europe, though the phylogenetic reconstruction in Blasi et al. (2019) suggests this is a recent phenomenon.

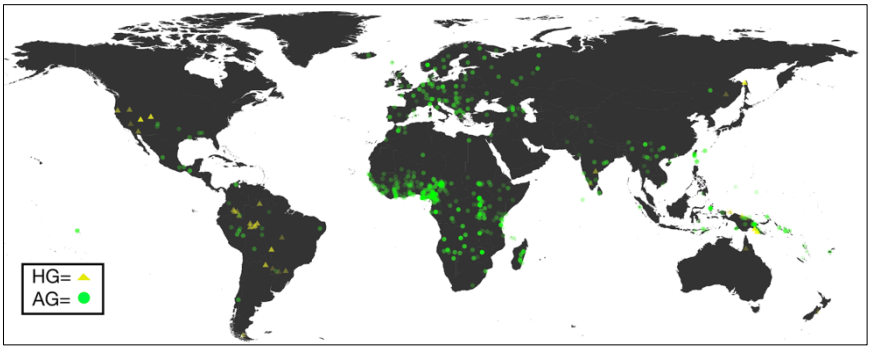

Figure 2. Locations of the languages in the top quartile of labiodental usage, judging from the occurrence of labiodentals in the word lists from the ASJP database. (Increased brightness corresponds to higher labiodental ratios.)

To control for the prevalence of labiodentals in some regions and the effect of large language families whose populations tend to rely on agriculture (e.g. Indo-European), we used a linear mixed effects model. The classifications of word lists into families and geographic regions was based on the AUTOTYP database, which utilizes a relatively fine-grained set of 24 independently motivated geographic regions. This limited the analysis to 1986 ASJP word lists. The *lmer* package in R was utilized with a random-intercepts approach. One model treated subsistence category as a fixed effect, while language family and geographic region were treated as random effects. Since labiodental ratios are technically bounded at 0 and 1, we used logit-transformed LR's as the dependent variable. In a null model, no fixed effect was provided and language family and geographic region were again treated as random effects. A likelihood ratio test contrasting the two models yielded a significant difference. Reliance on hunting and gathering affected the logit-transformed labiodental ratios ($\chi 2$ (1)=11.85, p=0.0006). (Intercept of fixed effect= -3.255, Correlation of fixed effect= -.309.) We interpret this result as strong additional support for Hockett's hypothesis. These results suggest that the clear disparity in labiodental ratios across populations with different subsistence strategies, evident in Table 1, is not simply due to confounds such as language contact and/or relatedness. Nevertheless, the results are based

on one linguistic database and one categorization of population subsistence strategies, so they should still be interpreted with caution. In the next section we discuss alternate methods we are utilizing to further investigate this apparent association. Preliminary results with those alternate methods also buttress the accounts of Hockett (1985) and Blasi et al. (2019).

4. Discussion and conclusion

Via a new approach, we have offered evidence that further supports the claims in Hockett (1985) and Blasi et al. (2019). Different sources of data for individual languages are being examined in follow-up work. In particular, we are analyzing texts from the Journal of the International Phonetic Association that also allow for typological breadth. These texts are not Swadesh-type word lists, but short transcribed stories. The results of the analysis of those texts thus far obtained are consistent with those in Table 1. In our follow-up work we are also using an alternate subsistence taxonomy, so that the results are not based too heavily on the classification of cultures in Güldemann et al. (2019). Additionally, the ongoing work focuses not just on labiodental ratios, but on word-initial labiodental ratios. We focus on word-initial sounds given their salience to transcribers and given that they are less likely to be affected by reductive processes. (Wedel et al., In press) We are also examining historical and comparative evidence for the exceptions that have presented themselves in the ASJP data, including a few key Amazonian test cases evident upon careful examination of Figure 2. Finally, our ongoing work includes phonetic analysis of actual individuals who have different bite types. These individuals are speakers of the same language (English), but preliminary work suggests they rely on labiodental consonants to differing degrees.

We believe the results of the present study offer additional support for the hypothesis detailed in Hockett (1985) and carefully followed-up on in Blasi et al. (2019). Labiodental sounds are less frequent in the speech of hunter-gatherers, judging from the rates of occurrence of consonants in common words. Ongoing work is helping to determine whether this pattern holds for other data sets, and whether completely different approaches also lend support to Hockett's intriguing hypothesis.

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References

Blasi, D., S. Moran, S.R. Moisik, P. Widmer, D. Dediu & B. Bickel. (2019). Human sound systems are shaped by post-Neolithic changes in bite configuration. *Science* 363.6432

Dediu, D. & S.R. Moisik. (2019). Pushes and pulls from below:Anatomical variation, articulation and Sound Change. *Glossa: A Journal of General Linguistics* 4.7. DOI: http://doi.org/10.5334/gjgl.646

Dediu, D., R. Janssen, & S.R. Moisik. (2019). Weak biases emerging from vocal tract anatomy shape the repeated transmission of vowels. *Nature: Human Behaviour* DOI: 10.1038/s41562-019-0663-x.

Everett, C. 2017. Languages in drier climates use fewer vowels. *Frontiers in Psychology* 8.1285. doi:10.3389/fpsyg.2017.01285

Everett, C. 2018. The global dispreference for posterior voiced obstruents: A quantitative assessment of word list data. *Language* 94.e311-e323.

Gordon, M. 2016. *Phonological typology*. Oxford University Press: Oxford.

Güldemann, T., P. McConvell & R. Rhodes. 2019. The language of hunter-gatherers. Cambridge University Press: Cambridge.

Hockett, C. 1985. Distinguished Lecture. *American Anthropologist* 87:263-281.

Shin, J., J. Kiaer & J. Cha. (2012) *The sounds of Korean*. Cambridge University Press: Cambridge. Chapter 6.

Wedel, A., A. Ussishkin & Adam King. In press. Crosslinguistic evidence for a strong statistical universal: Phonological neutralization targets word-ends over beginnings. *Language.*

Wichmann, S., E. Holman & C. Brown. 2018. The ASJP Database. Available at: https://asjp.clld.org/