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Mergers in Bardi: contextual probability and predictors of sound change

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Abstract: A crucial question for historical linguistics has been why some sound changes happen but not others. Recent work on the foundations of sound change has argued that subtle distributional facts about segments in a language, such as functional load, play a role in facilitating or impeding change. Thus not only are sound changes not all equally plausible, but their likelihood depends in part on phonotactics and aspects of functional load, such as the density of minimal pairs. Tests of predictability on the chance of phoneme merger suggest that phonemes with low functional load (as defined by minimal pair density) are more likely to merge, but this has been investigated only for a small number of languages with very large corpora and well attested mergers. Here we present work suggesting that the same methods can be applied to much smaller corpora, by presenting the results of a preliminary exploration of nine Australian languages, with a particular focus on Bardi, a Nyulnyulan language from Australia's northwest. Our results support the hypothesis that the probability of merger is higher when phonemes distinguish few minimal pairs.

Keywords: sound change; Australian languages; phonotactics; functional load.

1 Introduction

A crucial question for historical linguistics has been why some sound changes happen but not others. Recent work on the foundations of sound change has given us a picture of the types of phonetic and phonological structures that are predisposed to change. Such work has long concerned perceptual and production biases (see, amongst many others, Ohala 1992; Blevins and Garrett 1998; Garrett and Johnson 2013), but more subtle distributional facts about segments in the language, such as functional load, have also been argued to play a role in facilitating or impeding change (for example, Pierrehumbert 2001; Surendran and Niyogi 2003, Surendran and Niyogi 2006, Wedel et al. 2013a, Wedel et al. 2013b). Thus not only are sound changes not all equally plausible, but their likelihood depends in part on phonotactics and aspects of functional load, such as the density of minimal pairs.

A productive line of work in this area has concentrated on the differential probabilities of phoneme mergers (that is, the partial or total collapse of phonemic distinctions) in different positions in a word. However, the predictability of phoneme mergers has been investigated only for a small number of languages (for example, Surendran and Niyogi 2006; Wedel et al. 2013a). Here, we replicate these methods on a group of less-studied languages from Australia, concentrating on the Bardi language of north-west Australia. In particular, we test the robustness of findings drawn from data that involve citation forms and type (rather than token) data, since this is the material most likely to be available for large-scale comparisons for languages beyond the best resourced.

Questions about the origins of sound change are of particular interest for Australian languages, where we find remarkable stability in the phoneme inventories across languages from many different subgroups and

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families (see, among others, Gasser and Bowern 2014). Of course, stability in phoneme inventory composition is not the same thing as not undergoing sound change at all, but the homogeneity of Australian language inventories is striking, and in order to understand it, we need to understand the patterns of sound change we see across Australian families.

Here we present the results of a preliminary exploration of nine Australian languages, with a particular focus on Bardi, a Nyulnyulan language from Australia's northwest. To maximize comparability with previous work, we follow the procedures of Wedel et al. (2013a).[1] Bardi is a good choice for an exploration of this type because we already have data on reconstructed sound changes (Bowern 2004), including intervocalic loss of stops, as well as a phonemically transcribed dictionary (Aklif 1999). Moreover, in the history of Bardi sound changes, a few changes (such as the deletion of intervocalic stops) have led to extensive homophony in certain inflected verb forms. We show that despite substantial differences in the inventory size, composition, and phonotactic structure between the languages under study and those in previous investigations, the same tendencies hold. Lack of prior historical reconstruction using the comparative method for other Australian languages means that we cannot fully replicate Wedel et al.'s study for all languages under consideration, but we offer some comments on the distribution of minimal pairs in other languages in Section 5.

Wedel et al. (2013b) conducted a corpus study to examine the effects of phoneme frequency and minimal pair counts in the probability of phoneme merger. An example of a merger in English is those dialects where the phoneme /θ/ has merged with (and is realized as) the phoneme /f/, such that "fin" and "thin" are homophonous. Wedel et al.'s corpora contain 50,000 lemmas or more for each language and are from highly studied languages that have phoneme mergers documented in the historical record, including English, German, French, Korean, and Hong Kong Cantonese. The study compares the minimal pair counts distinguished by phoneme pairs that have an attested merger with those distinguished by phoneme pairs that have not undergone merger. They found that phonemes that distinguish a greater number of minimal pairs are less likely to merge, and that mergers are more likely between phonemes that do not contrast in minimal pairs very often and thus have a comparatively low functional load in the lexicon.

2 Materials

In the study presented here, we use data from a very different set of languages with much smaller datasets with which to test for effects of minimal pair and phoneme frequencies on sound change. We use data from nine Australian languages, as listed in Table 1 below. They represent a cross-sample of Australian families and well attested languages across Northern Australia.

Table 1: Language data used in the study.

Language	Family	Source	No. of lemmas
Bardi	Nyulnyulan	Aklif (1999)	4,815
Dalabon	Gunwinyguan	Evans et al. (2004)	3,634
Gooniyandi	Bunuban	KLRC (ms)	2,030
Gurindji	Pama-Nyungan (Ngumpin-Yapa)	Meakins et al. (2013)	4,956
Kukatja	Pama-Nyungan (Wati)	Valiquette (1993)	10,581
Ngarinyin	Worrorran	Coate and Elkin (1974)	7,922
Pintupi-Luritja	Pama-Nyungan (Wati)	Hansen and Hansen (1992)	6,035
Warlpiri	Pama-Nyungan (Ngumpin-Yapa)	Schwarz (1996)	9,940
Yanyuwa	Pama-Nyungan (Warluwaric)	Bradley (n.d.)	4,259

1 We are grateful to Andrew Wedel for sharing R scripts with us to facilitate this work.

All these materials are included in the Chirila lexical database (Bowern 2016). The languages represent a variety of areas of the country (illustrated by the map in Figure 1), from three Pama-Nyungan subgroups and four Australian non-Pama-Nyungan families). Kukatja and Pintupi-Luritja are both Wati languages, and Gurindji and Warlpiri are both Ngumpin-Yapa languages. These languages are among the best attested in the Chirila database.

Ideally, of course, we would compare our results from wordlist data to corpus data, but there are no extensive corpora for any Australian languages. Bowern's Bardi corpus materials contain approximately 120,000 words, but this material also includes sufficient codeswitching that it is inappropriate for a study like this without extensive cleaning. Other languages have corpora of a similar size, but are unpublished and/or undigitized. We recognize that the materials available likely limit the power of the conclusions that can be drawn, and that our data is not as representative of natural speech as we would like. As Wedel et al. (2013b: 180) noted, however, "the predictive value of phoneme probabilities based on word-type and word-token counts were not significantly different." This gives us confidence that data from wordlists may show signal, and that merger effects are not driven just by lexical frequency. Therefore, the absence of corpus data is unlikely to impact our findings.

There are a few idiosyncrasies of this particular dataset that are worth considering, especially since the dataset itself is so small and such idiosyncrasies might make a difference to the analysis. First, none of the mergers considered in this analysis are across-the-board, as most sound change in Australian languages has consisted of context-specific mergers with preservation of contrast in other phonological environments (cf. among others Dixon 1980). For example, /r/ and /l/ might merge before /k/, but a phonemic distinction between /r/ and /l/ is preserved in other environments, such as intervocalically. In our data, phoneme contrasts in the relevant merger context were counted separately from those in non-merger contexts; for none of the mergers was the minimal pair count zero (counts ranged from 1 to 4). Second, Bardi has 17 contrasting consonants distinguished by place and manner of articulation. Note that there is no voicing contrast, nor is there a contrast in aspiration or glottalization of stops. This is true for the other languages in the sample as well. Most of the consonant mergers considered in Wedel et al.'s study were a neutralization of contrast in voicing, aspiration, or glottalization, with only a few being mergers of consonants with different places or manners of articulation. Many other mergers in this study were vowel mergers, but most vowel pairs in the Bardi data were robust in the number of minimal pairs distinguishing them, suggesting that these are resistant to merger. Bardi has undergone vowel-assimilation changes (Bowern 2012) but no full vowel mergers. For example, plural verbs show regressive harmony where /a/ is raised to /i/ when the third

Figure 1: Map of languages used in the sample.

person prefix /i-/ is used. Furthermore, all phoneme pairs that differ in only one or two phonological features (suggesting they may be candidates for merger) have at least one minimal pair distinguishing them. For this reason, it was not possible to compare the probability of merger of phoneme pairs with minimal pairs versus those without, and results are reported only for the chance of merger in phonemes distinguished by minimal pairs.

3 Methods

After adapting the phonemic (IPA-based) orthography for the languages so that each phoneme is represented by one character, code was run in R (R Development Core Team 2015) to produce lists of minimal pairs, using a function that returns a Boolean value of `TRUE` for a pair of words that match in length and differ in only one character of the string. From this list, the frequency of minimal pairs distinguishing each phoneme pair was calculated.

After compiling this data, a logistic mixed effects model was run using the `lme4` package in R. The variables used in this model were coded based on whether there was a merger (the dependent variable); whether the contrasting pairs were between vowels or consonants; a binary value indicating whether a phoneme contrast was represented with minimal pairs at all; the raw totals of minimal pairs contrasting a pair of phonemes (scaled); and the log probability of the more probable phoneme in the pair (also scaled; independent variables). All phoneme contrasts (at least those within two features difference) were represented with at least one minimal pair, even those phoneme pairs which were merged in a certain context; i.e. no merger studied here completely eliminates the contrast between two phonemes in the context in which it applies. For this reason, we were able to run the statistical model for phoneme pairs that do distinguish minimal pair contrasts, but not those that distinguish no minimal pairs.

V-C contrasting pairs were deleted, so the data only considers V-V and C-C minimal pairs (no Australian language has a sound change, to our knowledge, where consonants vocalize or vowels become consonants). Some examples of V-V contrasts are /a/–/u/, as in *alur* 'cowtail stingray' and *ulur* 'mangrove tree', and /i/–/iː/, as in *pito* 'porcupine fish' and *piːto* 'paperbark'. Contrasting consonants include /k/–/p/, as in *kuwa* 'mermaid' and *puwa* 'insect', and /m/–/n/, as in *murru* 'sugar' and *nurru* 'firewood'. Some V–C contrasts that were omitted from this study include /u/–/p/, as in *rarru* 'little-shell turtle' and *rarrp* 'dawn', and /a/–/k/, as in *pola* 'little tide' and *polk* 'place near Beagle Bay'.

4 Results

The distributions of minimal pair counts for merged and unmerged phoneme pairs are shown in Figure 2. We show this only for Bardi, since this is the only language in our sample for which we have reconstructions of sound changes. As can be seen in Figure 2, phoneme pairs that have merged tend to have low minimal pair counts, while those that have not merged have more minimal pairs distinguishing them.

While participation in minimal pairs is one aspect of functional load, another is overall frequency in the lexicon. A frequency list was also generated for total phoneme frequency across the corpus, in order to calculate overall phoneme probability. In comparing minimal pair frequency and phoneme frequency, the more frequent phoneme of the pair that is contrasted was shown to be a better predictor of merger in Wedel et al. (2013b), and is used for the phoneme probability factor in this study as well. The distributions of the probabilities of the higher-probability phoneme of a pair for both merged and unmerged phoneme pairs are shown in Figure 3, and the distributions of the probabilities of the lower-probability phonemes for each pair are shown in Figure 4. In general, merged phoneme pairs have higher high-frequency and lower low-frequency phonemes in each pair than unmerged phoneme pairs do.

In assessing the relationship between minimal pair counts and phoneme frequency, we used the log of the higher-probability phoneme of the pair. As can be seen in Figure 5, there is a positive correlation ($r = 0.30$)

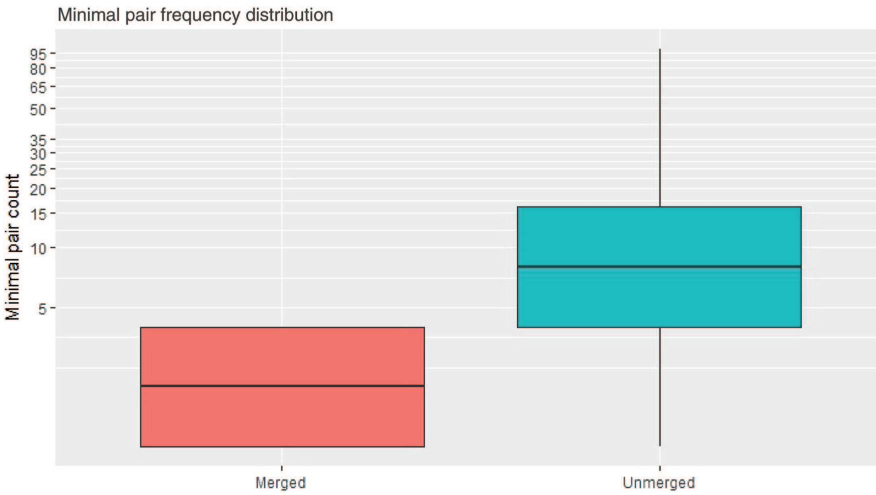

Figure 2: Distribution of minimal pair counts for merged and unmerged phoneme pairs.

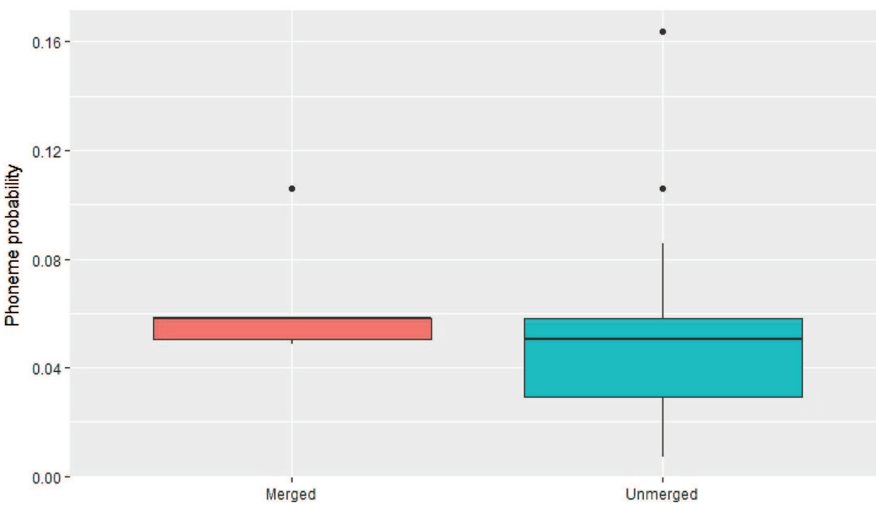

Figure 3: Probabilities of high-frequency phonemes for merged and unmerged phoneme pairs.

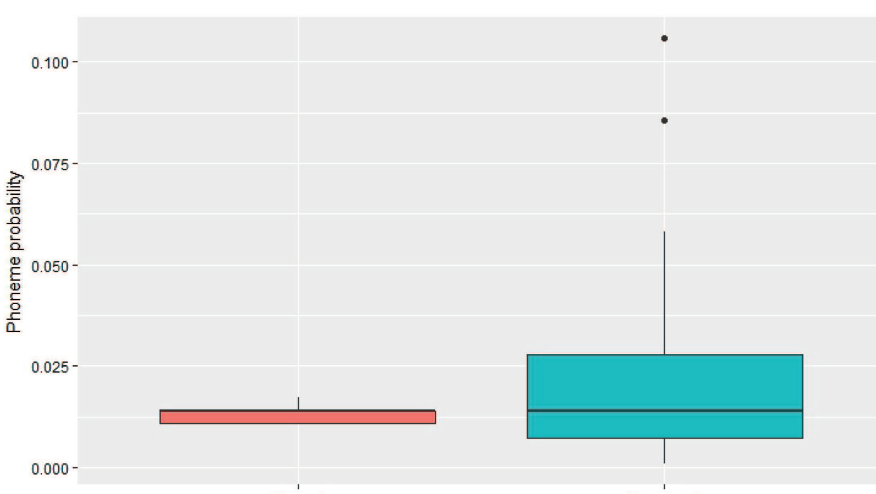

Figure 4: Probabilities of low-frequency phonemes for merged and unmerged phoneme pairs.

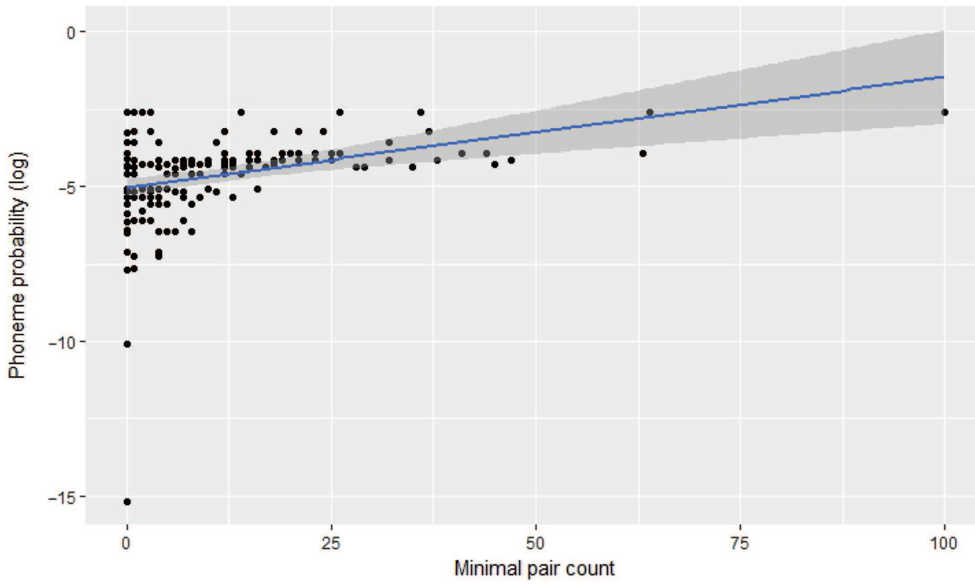

Figure 5: Linear relationship between minimal pair counts and log phoneme probability (for the higher-probability phoneme in the pair), from Bardi word list. 95% Confidence interval shown in shaded region.

between phoneme probability and number of minimal pairs. This is expected, as more frequent phonemes are likely to be more frequent in minimal pairs as well. Wedel et al. (2013b: 183) ultimately concludes that these variables are not inextricably linked, and phoneme probability is a weaker effect than minimal pair count.

The results of a logistic mixed effects model considering both the presence of minimal pairs and phoneme probability as predictors of phoneme merger are given in Table 2. The results of this model ($\beta = -7.52$, $z = -2.00$, $p = 0.045$) indicate that there is a decrease in the probability of phoneme merger as minimal pair count increases. An increase in phoneme probability, on the other hand, increases the probability of phoneme merger ($\beta = 1.18, z = 1.98, p = 0.047$). These results mirror the predictions made in Wedel et al. (2013b), albeit with greater standard error values.

In order to compare this model, which uses a minimal pair count factor and a phoneme probability factor, to models with only one of these two factors, we first ran the logistic mixed effects model both for a model with only a minimal pair count factor and for a model with only a phoneme probability factor. Then, we performed a model comparison (using ANOVA) tests in R, one comparing the performance of the minimal pair count model to the two-factor model, and one comparing the performance of the phoneme probability model to the two-factor model. The results of this comparison suggest that the two-factor model is a much better predictor of phoneme merger than a model considering only phoneme probability as a factor; there was an AIC of 48 with the frequency-only model, compared to base model 35.7 ($\chi^2 = 14.29, df = 1, p < 0.001$). In comparison to a model with only the minimal pair count factor, the two-factor model still performs better, but to a lesser extent than it does when compared to the phoneme probability model; there was a small but significant ($\chi^2 = 5.14, df = 1, p = 0.02$) difference in the AIC measure (38.9 versus 35.7 for the base model). These

Table 2: Fixed effects from logistic mixed-effects model.

Predictors	Estimate	Std. error	z Value	p-Value
(Intercept)	−7.75	2.76	−2.81	0.004[b]
Minimal pairs	−7.52	3.75	−2.00	0.045[a]
Phoneme probability	1.18	0.59	1.98	0.047[a]

Relevant mergers are split up into merger and non-merger contexts, and anomalous, i.e. V-C, phoneme pairs have been deleted. [a]Significant < 0.05; [b]significant < 0.01.

results suggest that the minimal pair count factor is a better predictor of merger than the phoneme probability factor is, but a model considering both of these factors performs better than either of these factors alone.

While the overall directionality of the predictions made in Table 2 are what we would expect, the predicted magnitude of the effect of both minimal pair counts and phoneme probability on merger is quite large. This is likely due to the smaller corpus size; each merger coded in the data has a larger effect on the model's predictions for a list of under 5,000 types than it would for a corpus of 50,000 tokens.

5 Further discussion and conclusions

This case study shows some of the issues that arise when studying sound change probabilistically in different language families around the world. The geometry of the phoneme inventory — the number of contrasts

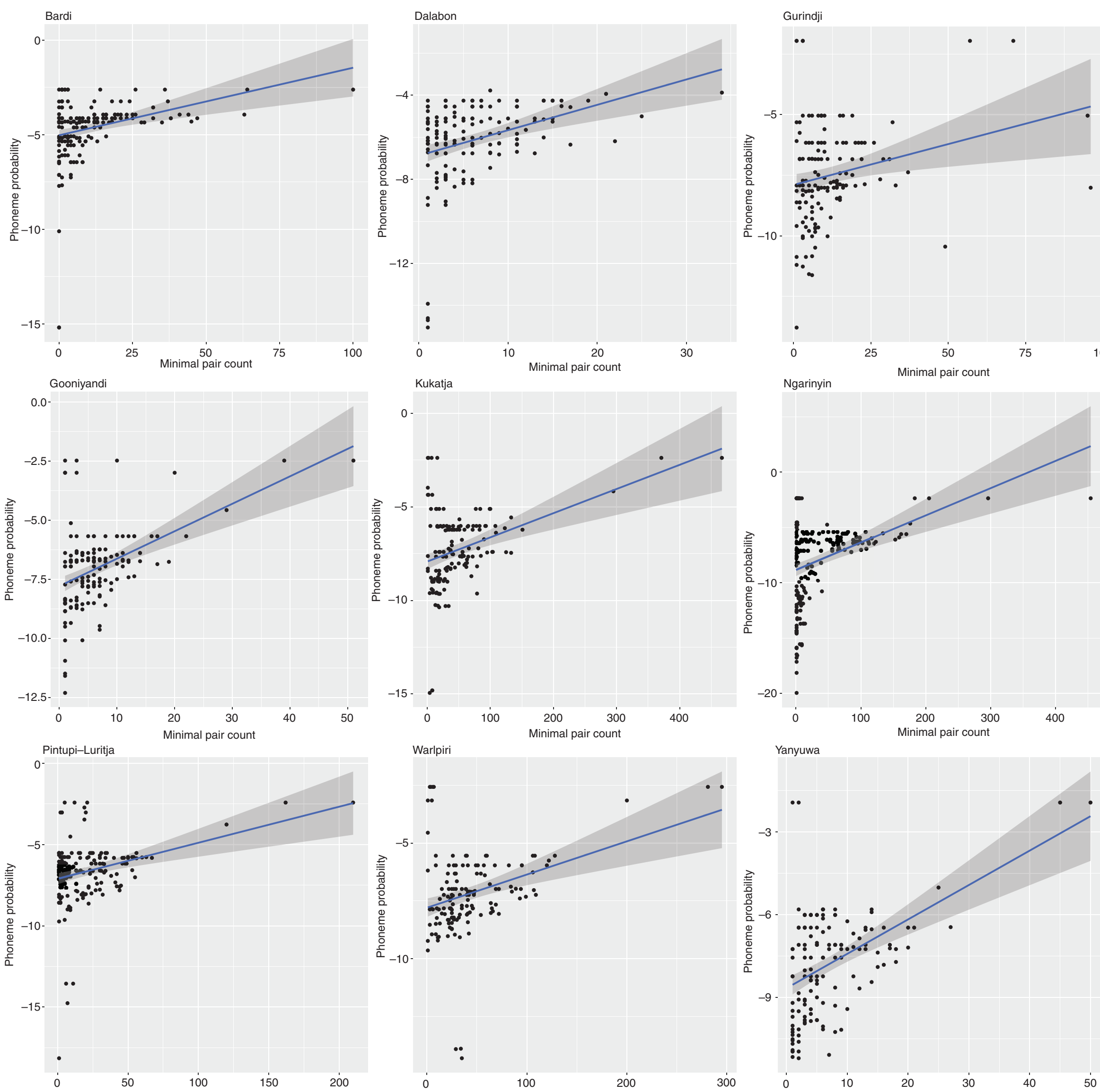

Figure 6: Scatterplots of linear relationship between minimal pair counts and log phoneme probability (for the higher-probability phoneme in the pair), using data from nine languages from Australia. 95% Confidence interval shown in shaded region.

and the presence of contrastive voicing, for example — affects how we are able to study whether contextual probability affects the likelihood of mergers.

Further work will examine the role of mergers for other languages. Preliminary findings suggest that the same results may hold, though the strength of the correlation clearly varies (consider Figure 6). The distribution of minimal pair contrasts (and therefore the functional load of phonemes) differs extensively across the dataset. For example, Ngarinyin has six times as many minimal pairs as Yanyuwa, when controlling for the number of items in the wordlist. Future work will examine the role of functional load and minimal pair density in sound change. Without attested or reconstructed sound changes in these subgroups, this limits the generality of our conclusions for Australia.

In conclusion, our findings suggest that Wedel et al.'s results generalize to wordlist data from Bardi. As Wedel et al. (2013b) noted, "the predictive value of phoneme probabilities based on word-type and word-token counts were not significantly different". The fact that we find the same patterns in word-type data from Bardi is further evidence that these patterns are both robust, and could potentially be found in a larger number of languages. In the Bardi data examined here, both minimal pair count and phoneme probability contribute to the likelihood of merger; however, the two together produce a model with significantly better fit than either factor alone.

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References

Aklif, G. 1999. *Ardiyooloon Bardi ngaanka: One Arm Point Bardi dictionary*. Halls Creek, Western Australia: Kimberley Language Resource Centre.

Blevins, J. & A. Garrett. 1998. The origins of consonant-vowel metathesis. *Language* 74(3). 508–556.

Bowern, C. 2004. *Bardi verb morphology in historical perspective*. Cambridge, MA: Harvard University dissertation.

Bowern, C. 2012. *A grammar of Bardi*. Berlin: Mouton.

Bowern, C. 2016. Chirila: Contemporary and historical resources for the indigenous languages of Australia. *Language Documentation and Conservation* 10(1). 1–45.

Bradley, J. n.d. Yanyuwa dictionary. ASEDA 0382 electronic file.

Coate, H. & A. Elkin. 1974. *Ngarinyin-English dictionary*. 2 vols. NSW, Australia: University of Sydney.

Dixon, R. 1980. *The languages of Australia*. Cambridge: Cambridge University Press.

Evans, N., F. Merlan, M. Tukumba & M. Arts. 2004. *A first dictionary of Dalabon (Ngalkbon)*. Maningrida, NT: Maningrida Arts & Culture Centre, NT.

Garrett, A. & K. Johnson. 2013. Phonetic bias in sound change. In A. Yu (ed.), *Origins of sound change: approaches to phonologization*, 51–97. Oxford, UK: Oxford University Press.

Gasser, E. & C. Bowern. 2014. Revisiting phonological generalizations in Australian languages. *Proceedings of the 2013 Annual Meeting on Phonology*. 1–10. https://journals.linguisticsociety.org/proceedings/index.php/amphonology/article/view/17 (1 July, 2018).

Hansen, K. & L. Hansen. 1992. *Pintupi/Luritja dictionary*. Alice Springs: IAD Press.

Meakins, F., P. McConvell, E. Charola, N. McNair, H. McNair & L. Campbell. 2013. Gurindji multimedia dictionary. http://ausil.org/Dictionary/Gurindji/ (4 February, 2017).

Ohala, J. 1992. What's cognitive, what's not, in sound change. In G. Kellermann & M. Morrissey (eds.), *Diachrony within synchrony: language history and cognition*, 309–355. Frankfurt: Peter Lang Verlag.

Pierrehumbert, Janet B. 2001. Exemplar dynamics: Word frequency, lenition and contrast. In J. L. Bybee & P. Hopper (eds.), *Frequency and the emergence of linguistic structure*, 137–158. Amsterdam: John Benjamins.

R Development Core Team. 2015. *R: A language and environment for statistical computing*. Tech. rep. Vienna, Austria: R Foundation for Statistical Computing. www.R-project.org.

Schwarz, S. 1996. Warlpiri-English dictionary. Electronic file. September 15, 1996.

Surendran, D. & P. Niyogi. 2003. Measuring the functional load of phonological contrasts. *arXiv preprint cs/0311036*. https://newtraell.cs.uchicago.edu/research/publications/techreports/TR-2003-12 (27 June, 2018).

Surendran, D. & P. Niyogi. 2006. Quantifying the functional load of phonemic oppositions, distrinctive features, and suprasegmentals. In O. Thomsen (ed.), *Competing models of linguistic change: evolution and beyond*, 43–58. Amsterdam: John Benjamins.

Valiquette, H. 1993. *A basic Kukatja to English Dictionary*. WA: Luurnpa Catholic School.
Wedel, A., S. Jackson & A. Kaplan. 2013a. Functional load and the lexicon: Evidence that syntactic category and frequency relationships in minimal lemma pairs predict the loss of phoneme contrasts in language change. *Language and Speech* 56(3). 395–417. http://journals.sagepub.com/doi/abs/10.1177/0023830913489096 (4 February, 2017).
Wedel, A., A. Kaplan & S. Jackson. 2013b. High functional load inhibits phonological contrast loss: A corpus study. en. *Cognition* 128(2). 179–186. https://doi.org/10.1016/j.cognition.2013.03.002. http://linkinghub.elsevier.com/retrieve/pii/S0010027713000541 (4 February, 2017).