DID PARTIAL HEARING LOSS SHAPE AUSTRALIAN PHONOLOGY? AN EMPIRICAL TEST USING SPOKEN ITERATED LEARNING

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Iterated learning experiments (where participants are trained on a miniature linguistic system then reproduce that system, with the reproduction being used as training for subsequent participants) form an important tool in evolutionary linguistics, and have been used to show how fundamental structural properties of language evolve through transmission (e.g. Kirby et al., 2008, 2015; Beckner et al., 2017). While iterated learning experiments have been run in acoustic and visual modalities (e.g. Verhoef et al., 2014; Motamedi et al., 2019), the foundational results on the evolution of compositional structure come from studies using written (typed) text. Since the neuro-congnitive mechanisms involved in reading and writing are not identical to those of spoken language (e.g. Huettig et al., 2018), replicating results in the spoken modality is necessary.

Moreover, moving to the spoken modality allows us to test hypothesised links between extra-linguistic biases affecting speech perception/production and the structure of spoken languages (e.g. Everett et al., 2016; Blasi et al., 2019). Here we test the intriguing proposal (Butcher, 2006) that certain typologically unusual properties of the consonant inventories of the Australian aboriginal languages – no *voicing* contrasts, few *manner*, but many *place* of articulation contrasts (but see Gasser & Bowern, 2014) – are due to the high prevalence, throughout history, of chronic middle-ear infections (*chronic otitis media* or COM) in aboriginal Australian children (World Health Organization, 2004). The proposal is that the ensuing hearing loss in a large proportion of the speaker population, mainly affecting the low and high frequencies where cues to voicing and manner contrasts reside, forced the Australian languages to adapt, dropping hard-to-hear cues and capitalising instead on the intact frequency regions (Butcher, 2006).

We report three experiments: *Experiment 1* replicates the "classic" iterated learning results from Kirby et al.'s (2008) Experiment 1 in the spoken modality. Participants were trained (using spoken stimuli) on a miniature language for describing patterned shapes and then asked to reproduce (in speech) the labels for those shapes. The initial participant in each chain was trained on randomlygenerated labels, but subsequent participants were trained on the labels produced by the previous participant. The spoken languages evolve over generations, becoming more accurately learned and developing systematic underspecification.

Experiment 2 tests two *dyad-based conditions* (following Kirby et al., 2015): two individuals are trained (simultaneously but in separate experiment booths) on the same target language, then interact using speech (via audio streaming between booths), taking turns to label objects for their partner or to select objects based on their partner's label. In the *Chains condition* the set of labels produced by one member of the dyad is used to train a new pair of participants at the next generation; in the *Closed Group condition* one dyad plays for many rounds, with no naive participants being introduced. Our results broadly replicate those of Kirby et al. (2015): structure gradually increases over generations in the Chains condition but is relatively flat across rounds in Closed Groups. However, we found far more variability in the spoken modality than in the written modality, including lower alignment between the members of interacting dyads.

Finally, *Experiment 3* focuses on testing Butcher's (2006) hypothesis: we contrast the Closed Groups from Experiment 2 (the *Unfiltered* condition) with a new set of Closed Groups (the *Filtered* condition) where a real-time band-pass filter (filtering out frequencies below 400Hz and above 4KHz, simulating the aftereffects of COM) was applied to all audio during training and interaction. While the languages which developed in *Filtered* and *Unfiltered* conditions looked broadly similar in terms of communicative accuracy, stability and structure, there were subtle differences in the consonant inventories used. While there was no difference in entropy of *manner* of articulation ($\beta = 0.02 \pm 0.03, p = .44$) or *place-of-articulation* entropy (i.e. no evidence for use a wider range of places of articulation under auditory filtering: $\beta = 0.02 \pm 0.03, p = .58$), Filtered dyads did have lower *voicing* entropy (i.e. a tendency for either voiced *or* voiceless consonants: $\beta = -0.03 \pm 0.013, p = .03$). This difference develop rapidly during communicative interaction and is in line with Butcher's hypothesis, providing preliminary empirical support for a role of COM in shaping some typologically interesting aspects of the phonology of Australian languages.

In sum, we show that iterated learning can be extended to the spoken modality, broadly replicating the previous findings and allowing us to test hypotheses concerning phonetic and phonological diversity, suggesting that the effects of COM might shape some aspects of phonology even within a single generation.

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