Ontogeny recapitulates phylogeny:
Child speech development as a microcosm of sound change

1. What can acquisition tell us about sound change actuation?

The notion that ontogeny recapitulates phylogeny in language development and language change has garnered attention throughout the history of linguistic inquiry (e.g. Schleicher, 1861; Grammont, 1902; de Saussure, 1915; see summary in Foulkes & Vihman, 2013). Common child patterns such as stopping, cluster reduction, final devoicing, and final consonant deletion are also well-attested in sound change (Locke, 1983). In the past, these parallels between development and diachrony have been interpreted as evidence that children's imperfect learning of the adult grammar might provide the driving force for language change (e.g. Sweet, 1888; Andersen, 1973). The hypothesis that sound change is driven by faulty transmission during acquisition has since fallen out of favor. This is partly due to areas of dissociation between child speech patterns and adult patterns of language change (Vihman, 1980) and partly due to a lack of evidence that adult speakers adopt pronunciation variants innovated by child speakers (Aitchison, 2003). But even in the absence of any causal relationship, there remain striking parallels suggesting that the study of sound change can be enhanced by evidence from child speech patterns, and vice versa. Sound change can be challenging to model due to extensive overlap and ambiguity between phonetic and phonological factors. The same problem arises in the accounts of child speech patterns: for example, the literature has seen extensive debate over whether child processes such as velar fronting should be seen as the product of performance limitations (e.g. Hale & Reiss, 1998, 2008), as purely phonological phenomena (e.g. Morissette, Dinnsen, & Gierut, 2003), or as the product of phonologization of performance constraints (e.g. Inkelas & Rose, 2007; McAllister Byun, 2012). By pursuing this last hypothesis, in which child speech patterns reflect grammaticalization of performance limitations, we encounter an actuation problem closely analogous to that faced by models of sound change. In the context of sound change, the key question is why sound change occurs in some languages where phonetic preconditions are satisfied, but not in others. In the context of child phonology, we ask why children who experience grossly similar phonetic pressures differ widely in how these pressures are phonologized. Below, we present a model that attempts to address the actuation problem as it appears in child phonology, followed by reflections on possible extensions to sound change over time.

2. The A-map model

The A-MAP MODEL was originally developed to explain how and why children pass through systematic, transient, non-adult-like phonological patterns en route to the acquisition of a mature L1 phonology. To strike a balance between phonetic detail and phonological formalism, we propose a constraint-based grammar that interfaces with an exemplar space populated by episodic traces of inputs perceived and outputs produced by the speaker. In the latter case, we assume that the stored traces represent both the motor plan executed and the associated acoustic consequences. Serving as the interface between the exemplar space and the formal grammar is a grammatical module termed the A(RTICULATORY)-MAP, which we describe in greater detail below. In line with conventional models, we assume that the child learner attempts to produce an output that is perceptually and/or featurally similar to the adult target. If the target requires complex motor control, though, the child speaker is likely to experience performance breakdowns that create considerable scatter in actual acoustic outcomes around the intended target. The cloud of stored forms representing the speaker's own output can thus be characterized not only in terms of its accuracy (how close is the center of the output cloud to the center of the cloud representing the perceived adult target?), but also its precision (are the traces tightly clustered or widely scattered?).

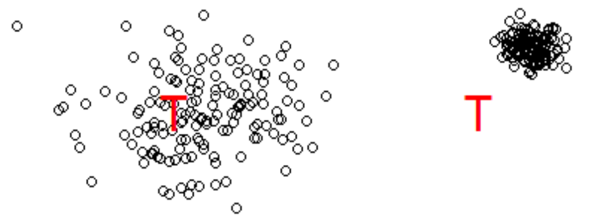

Figure 1. Accuracy vs. precision in the A-map

We propose that critical properties characterizing the distribution of a speaker's previous productions of a given speech target are indexed in the A-map. An entry in the A-map can be represented as a vector with three components: <*MP*, A_{mean}, A_{SD}>. *MP* represents a stored motor plan. (To be precise, it represents the average across previous executions of closely related motor plans, which cluster together based on their shared gestural properties. For simplicity, though, we will treat *MP* as a single motor plan that idealizes the properties of this cloud.) A_{mean} represents the location in multidimensional acoustic space of the center of the cloud of outcomes associated with past executions of motor plan *MP*. The value of A_{mean} is an average across the locations of all points linked to motor plan *MP*, weighted by the strength of activation of component traces. Finally, A_{SD} represents the standard deviation of the entire distribution of acoustic outcomes associated with past executions of *MP*. A_{SD} concisely encodes information about the reliability of the mapping between an intended gesture and the associated acoustic target.

We further propose that conventional feature-based grammars are enhanced by two constraints whose violation magnitudes are determined through reference to the A-map. The first is a faithfulness constraint, PMATCH, which penalizes a candidate in proportion to the distance between A_{mean} and the center of cloud representing the adult acoustic target, labeled T in Figure 1. The second is a markedness constraint, RECYCLE, which favors a candidate whose associated motor plan yields a precise, reliable mapping to acoustic space. We propose that the magnitude of the RECYCLE violation incurred by a given candidate is determined by A_{SD}: a broader, more scattered cloud incurs a greater penalty than a compact cloud. The RECYCLE violation is independent of the acoustic accuracy of the output relative to the adult target. In Figure 1, PMATCH prefers (A) over (B), while RECYCLE favors (B) over (A).

We call our markedness constraint RECYCLE because it can cause child speakers to reuse old forms that diverge from the adult target, even when the child is physically capable of producing a more adult-like output. In effect, we propose that RECYCLE can confer grammatical status on errors that originally arose as the consequence of performance limitations. A typical motor performance error involves substitution of a motor plan that is a simpler variant of the target plan, e.g. featuring omission of one component gesture. The simplified motor routine will not yield an exact match for the acoustics of the adult target, but it does offer a more reliable mapping between motor commands and acoustic outcomes. If the difference in A_{SD} between the output arising due to performance error and other, more faithful candidates is sufficiently large, RECYCLE will exert a grammatical influence in favor of the error form. Under the influence of this constraint, a performance error can go from sporadic to systematic and may also show sensitivity to phonological conditioning factors. Precisely this type of transition has been documented in cases of U-shaped learning in phonological development (e.g. Tessier, 2010; Becker & Tessier, 2011).

3. Analogies between sound change and child phonology in the A-map model

In this section we engage in a more detailed exploration of the similarities between child phonology and sound change, drawing on the A-map model set forth above. We frame this discussion in terms of the three core elements of phonologization discussed by Garrett & Johnson (2013): (a) the existence of structured variation, (b) constraints on selection, i.e. the fact that "linguistic factors influence the choice of variants," and (c) innovation, i.e. individual-level behaviors that initiate and transmit change.

Structured variation: Children are more susceptible than adults to the kinds of articulatory and perceptual pressures that give rise to variation in all speech communities. Thus, at the individual level, a child will produce a much broader pool of phonetic variants than a typical adult speaker. Garrett & Johnson emphasize that variation in adult speech output is not fully random; rather, pressures from domains such as motor control, aerodynamics, and perceptual parsing give rise to a biased distribution of phonetic variants. Child speakers share some of these same phonetic biases—for example, both children and adults are subject to the aerodynamic constraints that favor final devoicing. Other phonetic biases are specific to immature speakers, reflecting the influence of such factors as large tongue size and poor tongue-jaw dissociation. In total, the output of a single child can be seen as a microcosm of the structured variation found in an adult population, with predicted areas of dissociation deriving from child-specific phonetic pressures.

Constraints on selection: At the core of the A-map proposal is the notion that child speech is shaped by phonetic pressures, but the patterns that emerge reflect the computations of a phonological grammar. The A-map keeps track of variation in the child's own outputs, and RECYCLE favors candidates that have previously been realized reliably, i.e. with low variability in the mapping from motor plan to acoustic space. Some of these well-defined modes in acoustic space arise due to the influence of the phonetic biases described above. We thus encounter another clear parallel across the two domains of sound change and child speech: variation arises due to random change and is shaped by phonetic pressures, but grammatical constraints influence the selection of an output form from a wide set of candidates.

Innovation: Like members of adult speech communities, children can innovate or adopt new forms, and there is an element of unpredictability as to when a particular variant will catch on and propagate through a community or a child's idiolect. In the A-map model, children produce a range of forms due to errors in motor planning or execution. The forms that then take hold and propagate across the lexicon represent a locally optimal balance between two competing pressures: the pressure to use a form that can be realized with acceptable reliability (expressed through RECYCLE), and the pressure to match the acoustic properties of the adult target (expressed through PMATCH). When the difference in stability between the adult target and an alternative output is great enough that the influence of RECYCLE outweighs the influence of PMATCH, the grammar will favor a form that deviates from the adult target. Children whose grammar assigns a high weight to RECYCLE will tend to innovate (i.e. deviate) more often than children with high-weighted PMATCH.

An extreme example of innovation in child speech comes from the case of an English-learning female code-named C (Bedore, Leonard, & Gandour, 1994), who produced a dental click [ǀ] for the target coronal sibilants /s, z, ʃ, ʒ, ʧ, ʤ/. This pattern is difficult to explain in a conventional model of phonology, since the dental click is neither featurally nor articulatorily a good match for sibilant targets. However, as Bedore et al. point out, the high-frequency spectral energy that defines the class of sibilants is similar to the noise produced at the release of [ǀ]. In our A-map model, we can capture C's grammar as follows: at an early point in her development, C's attempts to produce sibilant fricatives routinely led to performance errors, with the result that the adult-like sibilant targets were highly penalized by RECYCLE. However, C also appears to have recognized that featurally similar substitutions, such as [t] for /s/, do not provide a particularly good perceptual match for a sibilant target. She was therefore driven to experiment with different variants that might differentiate her [t] for /s/ from her [t] for /t/. We assume that C happened to produce a dental click in the course of this exploration, which allowed her to observe that [ǀ] offers a perceptual match for the high-frequency spectral energy of /s/, but with a lesser degree of articulatory complexity. (Although clicks are cross-linguistically rare, they are described as relatively early-emerging sounds in languages whose inventories include them; e.g. Mowrer & Burger, 1991.) C is an example of a speaker who hit upon an unusual output in her effort to balance reliability in execution with accuracy in the acoustic match for the adult target. In general, the A-map model recognizes that individual children differ in their speech output histories, so the determination of the most stable form will necessarily vary across individuals. The role of chance and individual experience in determining a child's phonological patterns can be compared to the complex, non-deterministic relationship between phonetic precursors and phonologized patterns in sound change actuation.

4. A persisting influence of the A-map in sound change?

Is it possible that the same forces that drive child speech patterns can also account for some cases of sound change? As detailed above, there are clear parallels between our A-map model of phonological development and models that treat adult sound change as natural selection among competing variants (e.g. Blevins, 2004). In both frameworks, well-understood articulatory and perceptual pressures can induce variation and influence selection among variants. Our model differs in that the articulatory and perceptual pressures that influence the adaptive fitness of phonetic variants are given formal grammatical expression through RECYCLE and PMATCH. Crucially, we do not characterize these constraints as child-specific; it is not necessary to assume that they are eliminated as the child matures. Instead, the topography of the A-map shifts as the motor-acoustic mapping becomes stable across a wide range of targets over the course of normal neuromuscular maturation. For example, since motor control of the jaw matures earlier than control of the tongue, there is a meaningful difference in the reliability of a child's jaw gestures versus lingual gestures. For adults, though, both gestures are trivially easy to execute, and targets that were previously associated with different-sized violations of RECYCLE will now converge on similar values. After this leveling of the A-map, faithfulness/PMATCH will play the decisive role, leading to selection of the more accurate, adult-like form.

On the other hand, some of the pressures that lead to systematic errors in children remain present at a low level in adults, where they may drive gradient phonetic tendencies or sporadic speech errors. On the assumption that RECYCLE remains active in the constraint inventory, it may be reasonable to suggest that this constraint mediates some cases of phonetic drift in adults, potentially culminating in new phonological patterns. A promising candidate for such an analysis is consonant harmony, which Hansson (2001) has argued to have possible origins in speech errors. Systematic patterns of consonant harmony can be found in children, where assimilation involves major place of articulation, and in adults, where only minor place is involved. Both types of harmony bear a striking resemblance to patterns of assimilation in adult speech errors, e.g. *popcorn* → [kɑpkɔrn], *sunshine* → [ʃʌnʃaɪn] (Hansson, 2001). Young children, who are still mastering the motor skill of producing a sequence of similar but non-identical consonants, produce these errors with particularly high frequency. We proposed that in some cases, these errors make the motor-acoustic mapping sufficiently unstable that a systematic pattern of consonant harmony arises through the influence of RECYCLE (McAllister Byun & Inkelas, 2012). Although children quickly overcome the motor difficulty associated with alternating between major places of articulation, errors may persist in the more challenging context of alternating between similar segments that differ only in minor place. It is conceivable that the likelihood of error is just great enough, and the perceptual mismatch created by the error just small enough, that a RECYCLE-mediated pattern of CH for minor place of articulation could persist through much of childhood. The pattern might then be learned by the next generation as a regular property of the phonological grammar.

5. Conclusion

Somewhat obscured under traditional descriptions of a child's acquisition of phonology are incremental sound changes that in many ways parallel those occurring within adults. The same processes of variation, competition, and selection can be identified as child pronunciations shift over the first several years of life. The changes that occur in childhood are typically much greater in magnitude than any changes exhibited over the adult lifespan. Thus, child speech development can be regarded an improved lens through which to view the actuation of a sound change: the changes are more dramatic and unfold quickly enough that they can be observed in real time within individuals, not just inferred from cross-sectional population data. We conclude, resonating with Ferguson and Farwell (1975), that even though children's phonological development and adult sound change have traditionally been studied under separate rubrics, they operate under many of the same influences; cross-fertilization between the two areas of study should thus be encouraged.

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