DOI: 10.26346/1120-2726-146

Vowel reduction: A usage-based perspective

Vsevolod Kapatsinski,[a] Shelece Easterday,[b] Joan Bybee[c]

[a] Department of Linguistics, University of Oregon, USA <vkapatsi@uoregon.edu>
[b] Laboratoire Dynamique du Langage, CNRS & Université de Lyon 2, France <shelece.easterday@cnrs.fr>
[c] Department of Linguistics, University of New Mexico, USA <joan.bybee@gmail.com>

From a usage-based perspective, reduction results from automatization of stored gesture sequences corresponding to words and phrases, which accompanies reuse. In this paper, we discuss the mechanisms of and constraints on automatization, and examine its consequences for vocalic gestures in prosodically weak positions in a typologically and genetically diverse language sample. We show that vowels shorten, devoice, unround, and centralize (with some raising). These kinds of reductions are late-acquired speech patterns which represent highly skilled behavior that results from extensive practice. Reduction is also intricately conditioned by the discourse context. We argue that the leaders of reductive change are adults, who know when and how to reduce in ways sanctioned by the speech community, and have the social cachet to influence other speakers. Reductive change is not due to imperfections in intergenerational transmission. Rather, it is the outcome of lifelong optimization of goal-directed movement patterns constrained by feedback from interlocutors.

KEYWORDS: usage-based, sound change, automatization, vowels, reduction, social selection, reinforcement learning, crosslinguistic.

1. Theoretical background

Vowel reduction is one of many types of reduction observed in sound change and phonological processes. In fact, sound change and synchronic processes seem to be dominated by reductions of various sorts. Mowrey & Pagliuca (1995) propose that sound change can be characterized as either substantive or temporal reduction of articulatory actions, one result of which is overlap of articulations. Bybee & Easterday (2019) use a crosslinguistic database of over 800 processes from 81 languages to test whether increase or decrease in the degree of constriction in consonants occurs more frequently and find that indeed, a decrease in the degree of constriction is more common. In fact, cases of increase in the degree of constriction are largely limited to glides becoming obstruents (see section 3).

The ubiquity of reductive changes and their phonetic content has major implications for theories of language change generally. While language change is often ascribed to imperfect transmission and, therefore, reanalysis and/or innovation on the part of young children (Lightfoot 1999, Blevins 2004, Hudson Kam & Newport 2005), reductive sound change cannot be explained in this way. Children and adults 'simplify articulation' in different ways. In particular, vowel reduction patterns seen in human languages are not mastered by children until late in development (Redford 2015). Unstressed vowels in child speech are longer and less centralized than in adult speech, including child-directed adult speech. For example, Pollock *et al.* (1999) showed that unstressed syllable durations decreased over development while stressed syllable durations stayed constant. Several studies observed longer and less reduced function word productions in children compared to adults, at least up to age 8 (Allen & Hawkins 1978; Goffman 2004). Redford (2015) notes that reduced movements are a characteristic of expert motor control across domains of motor performance. Furthermore, adults not only can reduce but also know when to reduce, flexibly deploying hypo- and hyperarticulation (Lindblom 1990). This knowledge also takes a while to develop. For example, unlike adults, English-speaking children do not systematically emphasize words when they repeat them upon being misunderstood (Redford & Gildersleeve-Neuman 2009). Chen (2011) found that Dutch children do not systematically mark prosodic focus until age 8. The kinds of reductions we observe in diachrony are largely adult-like, supporting a fundamental claim of usage-based linguistics, that grammar emerges out of language use. They begin in reduction-favoring discourse contexts that favor hypoarticulation, and involve the vowel reduction patterns that demand mature motor control.

If language change were mostly driven by imperfect transmission, languages would have evolved in the direction of child speech, increasing the durations of unstressed syllables. Instead, sound change appears to be driven by automatization of production, as it happens first in the more automatized speakers and action sequences. It is led by expert producers, who know when and how to reduce, and it advances fastest in the most well-practiced, entrenched and automated action sequences – frequent words (Hooper 1976; van Bergem 1995; Bybee 2000; Bybee *et al.* 2016; Hay & Foulkes 2016), the very words that are least likely to undergo changes driven by imperfect transmission across generations (Hooper 1976).

Some contexts favor reduction while others disfavor it (Lindblom 1990). Reduction-favoring contexts include rapid speech, casual speech style, and lack of discourse and information-structure prominence, as well as phonological environments that make the target sounds difficult to articulate. As an action sequence is reused under reduction-favoring circumstances, it continues to accumulate reduced pronunciation variants. Subsequently, it can be produced in a reduced form even when used outside of its usual context (Bybee 2002; Brown & Raymond 2012; Seyfarth 2014; Hay & Foulkes 2016). More rarely, words that are used in contexts that disfavor reduction or favor lengthening (e.g. adjacent to intonational unit boundaries, or when conveying new or emphasized information) can also become less reduced over time. In a diachronic study of New Zealand English, Sóskuthy & Hay (2017) show that words that increase in frequency tend to get shorter, but some other words lengthen. These are words that become less predictable from context over time (increasing in information content) and those increasingly used in utterance-final position associated with final lengthening.

Over time, almost every speaker learns which words should and should not be reduced, and what ways of reduction are socially sanctioned. Never reducing *I don't know* or flapping the /t/ in *butter* marks one as a non-native speaker of American English, while not flapping in *emitter* is relatively unremarkable (Kapatsinski 2014). Detailed phonetic knowledge developed by individuals is transmitted from generation to generation as part of the community norms. Thus phonetic variation in online production may not always just attend to the immediate needs of the participants but also be influenced by subtle aspects of past usage. We now discuss how such social constraints on reduction may be transmitted from generation to generation.

1.1. Selective pressures in reductive sound change

Change is the result of variation and selection. At any given point, any particular message is associated with a range of pronunciations. Only some of the pronunciation variants are perceptually distinct but all of them are subject to selection pressures. Explaining the recurrent directions of change therefore requires specifying the selection pressures operating on pronunciations.

From a learning-theoretic perspective, articulations that are reinforced should be produced with increasing probability while those that are 'punished' should reduce in frequency. 'Punishment' is used here in the technical sense of an undesired consequence following an action which makes the action's reuse less likely (Skinner 1981; Sutton & Barto 1998). One source of punishment in speech production is articulation difficulty. However, as noted above, childlike mispronunciations seldom drive language change. Therefore selection cannot be driven entirely by this factor.

Another important source of punishment and reinforcement is the speech community, as represented by one's interlocutors, who can (sometimes subtly) reward the pronunciations that have social cachet (e.g. by treating a British-accented speaker as smart) or punish the pronunciations that are not so valued. Social rewards begin in infancy, when caretakers are more likely to respond to babbling infants when they produce more target-like sounds, and infants appear to be highly sensitive to this reinforcement, which shapes them into adopting the pronunciation norms of their speech community (Goldstein *et al.* 2003, Warlaumont *et al.* 2014). Interlocutor feedback continues to affect speaker choices in adulthood. For example, speakers react to being misunderstood by hyperarticulating cues that distinguish the word they intended to produce from the word it was misperceived as, an articulatory adjustment that persists across a substantial delay (Buz *et al.* 2016).

While overt incomprehension signals are relatively rare in the constrained context of everyday speech, subtle social reactions are ubiquitous. In fact, lack of intelligibility can give rise to positive social feedback for some speakers because of its correlation with and resulting associations with masculinity (e.g. Hefferman 2010). On the other hand, relatively unintelligible children can be judged as disordered and unlikable (Redford *et al.* 2018). If a social evaluation is picked up by the speaker, it can influence their future production choices. When it is not (e.g. in autism; Warlaumont *et al.* 2014), atypical productions persist.

For articulatory variants to be differentially reinforced by one's interlocutor, they must be perceptually distinct and salient enough to attend to (see Steriade 2001). Imperceptibly different articulations are instead selected for reproduction on articulatory grounds alone. Therefore, articulatorily-motivated, automatizing sound changes are particularly likely to affect low-salience sounds, including unstressed vowels.

Importantly, social feedback is largely arbitrary: sounds that are stigmatized in one speech community are prestigious in another. Therefore, sound change driven by social feedback can proceed in many different directions. Thus, the same or similar stressed vowels can raise and lower in different dialects of the same language, and even switch places in the acoustic space (e.g. the vowels in *pin* and *pen*; Labov 2006). In contrast, sound change driven by automatization is necessarily directional, allowing for strong generalizations regarding recurrent diachronic pathways.

1.2. Discourse context and intentional variability

Reduced speech that leads to sound change is not lazy or sloppy, it represents a highly skilled behavior that conforms to community norms (Lindblom 1990; Bybee 2012; Pouplier 2012). While automatization leads to fluency and efficiency, an important component of skilled execution is not reducing in excess. A well-practiced musician does not skip the notes of a familiar piece of music. Practice increases maximum speed, making it possible to perform the piece faster. However, performing the piece faster is not necessarily the goal of practice. Instead, the goal is to increase control over the production of the necessary elements of the piece, minimizing unintended variation but maximizing intentional variation (Bryan & Harter 1897), so that one can slow down or speed up, crescendo or decrescendo, and emphasize certain notes for expressive purposes.

The need to manipulate the signal for expressive purposes provides an important constraint on reduction. For example, the speaker can choose to emphasize and over-articulate certain elements for the expression of emotion. Degrees of reduction can also signal grammatical or semantic distinctions. Barth-Weingarten & Couper-Kuhlen (2011) find that verb-*and*-verb constructions in English conversation have a more reduced variant of *and* and more fusion in the phrase if the speaker intends to signal a single action rather than two actions, as in *came 'n delivered something.* Fowler *et al.* (1997) and Vajrabhaya (2015) show that durational differences between mentions of the same word are conventionalized cues to story structure, controlled by discourse coherence rather than accessibility of the words to either the speaker or the listener. These durational adjustments then constitute intentional variability. In contrast to unintended variability, intentional variability increases rather than decreases with increasing experience (Bryan & Harter 1897). As one would expect from this perspective, Bell *et al.* (2003) show that the effects of repeated mention are greater in frequent words.

Although frequent words tend to lead reductive sound change (Bybee 2000; Hay & Foulkes 2016). Tomaschek *et al.* (2013, 2018) found that stressed vowels of frequent, well-practiced German words are not reduced but instead articulated more precisely than those in rare words when the words are pronounced in isolation. Yet, the opposite result is often obtained when words are pronounced in context (e.g. Tomaschek *et al.* 2018). A possible explanation for these conflicting results is that the 'important' parts of frequent words are akin to the necessary elements of a musical piece, in being neither more or less reduced with increasing experience but rather easier for the speaker to control.

Speakers hyperarticulate for a variety of reasons: new, less predictable items, pre-pausal items, and items indicating affect are all protected from reduction (Lindblom 1990). As a result, most lexical words are at times pronounced in contexts disfavoring reduction, ensuring that nonreduced tokens of these words continue to be represented in memory and remain available for selection, whether driven by social prestige, discourse function or even aesthetic preference. Their availability for selection is likely the main reason that prevents a rapid move towards reduction.

1.3. Crosslinguistic and language-specific patterns

Usage-based theory holds that all types of linguistic structure – from constructions to phoneme inventories – are emergent from the processes of change that are ongoing in all languages. Since change creates these structures, it also constitutes an important element in the explanation for why these structures are the way they are. Thus the focus of explanation in a usage-based theory is on the processes of change more than on the outcome of change.

Detailed production routines are acquired from the language user's community. These patterns have language-specific characteristics that are important to describe in phonetic detail. Patterns of reduction are not immune to social selection and therefore may be partially arbitrary from a phonetic point of view. Largely unconsciously, the speaker growing up in a community does a spectacular job of adopting the phonetic detail that is modeled in the environment.

Nonetheless, crosslinguistic patterns of automatization (including patterns of vowel reduction) have important similarities that have to do with the fact that automatization is also constrained by the universal characteristics of the human vocal tract and motor control systems. These similarities allow us to study the reductive changes observed in the languages of the world as a window on the consequences of automatization. A report on such a study follows.

2. Vowel reduction across languages

2.1. Data

The vowel reduction processes we report on here are collected in AlloPhon, a crosslinguistic database of sound change (Bybee & Easterday 2019). AlloPhon consists of all allophonic (phonetically-conditioned) processes reported in the phonological references consulted for a genealogically-stratified sample of 81 languages, which in turn is heavily based on the sample used in Bybee, Perkins & Pagliuca (1994). The deliberate diversification of the language sample and consideration of synchronic rather than reconstructed or attested historical patterns serve to minimize biases towards languages with a long history of writing and description, and allow for the testing of hypotheses regarding sound change on a broad crosslinguistic scale. The sampling procedure distinguishes AlloPhon from other databases, such as Mielke (2008), Crosswhite (2001) or Barnes (2006), which are based on convenience samples.

The design features of AlloPhon also distinguish our methodological approach from previous typological studies of vowel reduction (Crosswhite 2001, Barnes 2006). Because these surveys are limited to languages already known to have the relevant vowel reduction patterns, the resulting samples are heavily skewed towards Slavic and Romance languages. In contrast, the AlloPhon database was constructed independently of the specific research questions examined here and can be used to establish relative worldwide frequencies of various vowel reduction phenomena and their properties. Additionally, both Crosswhite and Barnes distinguish phonetic and phonological (specifically neutralizing) processes and focus on the latter while our interest is on processes that are purely allophonic, revealing finer phonetic details of ongoing vowel reduction patterns.

2.2. The survey

The current report takes vowel reduction to include quality reduction, shortening, devoicing and deletion. The latter three of these processes we examine in all 81 languages and assume without further comment to be reductions, but changes in vowel quality are not necessarily all reductive. For that reason, to arrive at a set of vowel quality changes that could be considered reductive, we excluded quality changes conditioned by the place of an adjacent consonant, conditioned by an adjacent vowel or a vowel in another syllable, or restricted to an open or closed syllable. Also excluded were cases of coalescence, glide formation, and changes in offglide quality. Thus the quality changes we are interested in are conditioned by lack of stress only. This means that the quality changes surveyed occur only in languages with word stress, which are 66 of the 81 languages in AlloPhon. Some of the excluded quality changes can also be considered reductive (for example, changes resulting in vowel harmony) but they are excluded here in an attempt to delineate the range of quality reduction independent of surrounding context. Although the quality changes we study here are limited to those in unstressed syllables, we do not mean to imply that quality changes in stressed syllables cannot be reductive. Bybee (2015) lists some ways that vowel shifts appear to be reductive; see also section 3.2. Rather, unstressed syllables are the focus of this work because they are prime loci for reduction: they are shorter and draw less attention from both speaker and listener, resulting in gestural undershoot and hypoarticulation (Lindblom 1963, 1990). The full set of processes included in the survey is shown in the Appendix.

2.2.1. Centralization, unrounding and vowel height changes

The most commonly mentioned quality change in unstressed positions is centralization, that is a movement on the front-back dimension away from the periphery. Centralization is very often described as accompanied by change in the high-low dimension towards the mid-range. In five languages, all vowels are centralized in unstressed positions. In Maidu (Shipley 1964: 11), Island Carib (Arawakan family; Taylor 1955: 236-237), and Pech (Holt 1999: 18) all vowels centralize or become 'lax' while remaining distinct. In Guaymí (Lininger Ross 1981: 104-105) and Gugada (Platt 1972: 25) vowels in unstressed syllables all reduce to schwa. In Pangasinan, three of the vowels, /i u a/, reduce to [ɪ ʊ ə] when unstressed (Benton 1971: 7). In all of these cases, the vowels are both centralized and reduced to a mid position. In one additional language, centralization affects one high and one low vowel (/a/ and /i/ > [ɐ] and [ɪ], respectively, in Moro, Black & Black 1971: 9, 11) while the height distinction is maintained.[1]

In five languages, the reduction pattern includes both centralization and raising, as only the low vowels are affected. In Yimas (Foley 1991: 45), Gugada (Platt 1972: 8), Alyawarra (Yallop 1977: 25) and Karok (Bright 1957: 11), a low vowel /a/ or /ɑ/ is raised to [ʌ] or [ə]. In Nimboran (Anceaux 1965: 13) the 'low central' vowel becomes 'mid open'.

In two languages, only high vowels are reduced, becoming mid (Ningil, Manning & Saggers 1977: 58-59; Zuni, Newman 1965: 14). In Ningil, the high central vowels become schwa, while in Zuni tense high vowels become lax.

In contrast, in two languages, mid vowels raise when unstressed (Kadiwéu, Sandalo 1997: 16; and Ternatean, Hayami-Allen 2001: 40). In Kadiwéu, /ɛ/ and /ɛː/ raise to [e] in word-final position, which is unstressed. In Ternatean, /o/ raises to [u] in antepenultimate position, with stress falling on the penultimate syllable. In these cases no centralization is mentioned.

On the front-back dimension we found no instances of backing or fronting beyond the central position. Similarly, while lowering occurs in the sample, there are no instances of lowering beyond the mid position. To verify the robustness of this generalization, we have also searched a second database, P-Base (Mielke 2008) for unconditional patterns affecting vowels [+syllabic]. We found only one apparent example of lowering below the mid position, the lowering of /e/ and /o/ to [a] in Sacapultec. However, reading of the primary source (DuBois 1981: 146-147) indicates that this is a morphophonemic rather than allophonic process, as [e] and [o] do occur in unstressed syllables.

Another possible example is the apparent lowering of /o/ to [ʌ] in the immediately pretonic position in some dialects of Russian and other East Slavic languages. However, there are reasons to doubt that lowering was actually involved in this process. First, modern Slavic /o/ derives from Proto-Slavic long /a/; if it never raised in a given language, no lowering is necessary. Thus, Kasatkin (2010) argues that the rounded vowel was a low /ɔ/, and the pretonic [ʌ] is the result of unrounding. Krasovitsky (*this issue*) documents the emergence of the /o/-/a/ merger in a dialect with a relatively high /o/ but likewise shows that the change involves unrounding of /o/ and raising of /a/, and not lowering of /o/. There is one language in our sample in which reduction unrounds an unstressed /o/ (Nimboran, Anceaux 1965: 14). Unrounding is reductive because it results in the elimination of a labial gesture.

Second, the pretonic position involves some degree of prominence, possibly shared with the following stressed syllable. Barnes (2006, 2007) reports that pretonic vowels are as long as under main stress. In truly unstressed positions, both /a/ and /o/ are centralized to [ə]. It is possible that, in some dialects, the pretonic [ʌ] resulted from lowering the schwa under (secondary) stress (Brok 1916; Knjazev 2004: 24). Indeed, Barnes (2007) shows that hyperarticulation, elicited using listener misperception, results in lengthening and lowering an unstressed schwa towards an [ʌ]. In unstressed syllables in modern Russian, it is height that distinguishes the schwa from other vowels that can occur in that position, which are all high. Targeting especially low tokens of [ə] is therefore expected under hyperarticulation (Kapatsinski 2018). As stress is often argued to be phonologized hyperarticulation (e.g. de Jong 1995), Barnes' data provide support for the viability of this diachronic pathway.

Thus, our results provide no support for the idea that vowel reduction can be centrifugal, making unstressed vowels more peripheral (Crosswhite 2001; Harris 2005). While apparent synchronic examples of centrifugal reduction exist, we contend that they do not in fact result from reductive sound change.

2.2.2. Shortening

While we suspect that truly unstressed syllables are universally shorter than stressed syllables, to varying degrees, such context-independent shortening does not generally make it into phonological descriptions as a vowel reduction process because it is described as a correlate of stress. However, eight languages are described as having (further) context-specific shortening of unstressed vowels, which occurs in specific environments. As there are no languages where shortening preferentially affects stressed vowels, these data suggest that unstressed vowels are more susceptible to further context-specific shortening.

In our sample, the languages with context-specific shortening of unstressed vowels include Island Carib, where /i/ becomes shorter, laxer, and partly devoiced when unstressed between consonants (Taylor 1955: 236-7) and Selepet, where vowels become shorter in a pre-tonic position (McElhanon 1970: 6). In Pech, long vowels shortened only in unstressed and/or closed syllables (Holt 1999: 18). Barnes (2006) also found shortening in unstressed syllables, though he was only interested in cases in which a phonemic difference between long and short vowels was neutralized.

In addition to shortening as a rhythmic response to duration as a correlate of stress, there are cases in which the shortening could be the consequence of anticipating a glottal gesture associated with a pause, voicelessness, or a glottal stop. In our sample, vowels shorten before glottals or voiceless consonants in three languages (Sapuan, Jacq & Sidwell 1999: 11; Kadiwéu, Sandalo 1997: 17; and Nicobarese, Braine 1970: 51). In one case, a pause appears to condition shortening: in Ma'ya, vowels with a 2-1 tone shorten sentence-finally (Van der Leeden 1993: 62). These processes could also be the consequence of reducing a glottal gesture associated with vowel voicing.

2.2.3. Devoicing

An anticipation of a glottal opening gesture associated with a consonant or a pause can also result in full or partial devoicing of the preceding vowel (Browman & Goldstein 1992; Jannedy 1995; Delforge 2012). Similarly, devoicing of a vowel can result from a reduction in the vocalic glottal closing gesture, which closes the vocal folds just enough to generate voicing. If devoicing is driven by a reduction in the vocalic closing gesture, we would expect it to preferentially occur when the gesture is both followed and preceded by open vocal folds.

Devoicing is observed in 11 languages in the sample, comprising 32 processes. In Karok, short vowels are 'whispered' in a post-tonic syllable before a pause, while long vowels become glottalized (Bright 1957: 13). In Cheyenne, unaccented vowels become voiceless in six different environments (Frantz 1972: 9). In Cocama, vowels become voiceless when unstressed (Faust & Pike 1972: 9), as well as in initial position. In Jivaro, unstressed vowels are voiceless between voiceless consonants belonging to the same word (Turner 1958: 16-17). In Toqabaqita, unstressed vowels are variably devoiced word-finally and between voiceless consonants (Lichtenberk 2008). In Modern Greek, unstressed vowels following a voiceless consonant are voiceless before a pause (Householder *et al.* 1964: 14). In Tojolabal, vowels become partially voiceless utterance-finally (Furbee-Losee 1976: 191). In Tohono O'odham, ten different devoicing processes are reported by Hale (1959: 17-23).

Some processes affect only high vowels, which appears to be cross-linguistically common (Greenberg 1969; Jaeger 1978; Gordon 1998). This is attributable to their shorter duration and the fact that voicing requires high airflow through the vocal folds and the constriction associated with high vowels reduces airflow (Ohala 1983; Gordon 1998). Thus, in our sample, there are three languages in which only high vowels are devoiced (West Greenlandic, Fortescue 1984: 335; Island Carib, Taylor 1955: 236-237; Uighur, Hahn 1991: 34-35, 42-43). In all three cases, this process occurs between voiceless consonants, and in the latter two it is additionally restricted to unstressed syllables. These data therefore suggest that most devoicing processes are the result of reduction in the magnitude, i.e. formant undershoot (Lindblom 1963), of the vocalic glottis closing gesture. Unstressed vowels appear to be particularly susceptible to this kind of reduction, which is not observed to preferentially target stressed vowels in any language. The results are consistent with the findings of Gordon (1995), which used a convenience sample of languages known to have non-modal vowels.

2.2.4. Deletion

The most extreme type of reduction is deletion. Eight languages in our sample exhibit unstressed vowel deletion across vowel qualities. These include Guaymí and Ternatean, where all unstressed vowels variably delete (Lininger Ross 1981: 105; Hayami-Allen 2001: 38-39). In some languages, deletion appears to be categorical in specific contexts: Jivaro, where unstressed vowels devoice or elide between voiceless consonants and in a 'final contour', likely corresponding to the utterance-final position (Turner 1958: 16), Alyawarra, where short vowels delete before sonorant consonants (Yallop 1977: 27), Pech, where unstressed vowels are deleted between stressed syllables and between a consonant and /r/ (Holt 1999: 23), Carib (Cariban family), where unstressed vowels delete word-initially in the second word of a compound (Courtz 2008: 31), Karok, where short vowels delete word-initially preceding a consonant cluster, and Selepet, where vowels delete in post-tonic position (McElhanon 1970: 6).

Our sample also contains five languages in which only some vowels are deleted. A common pattern is high vowel deletion, though mid central vowels also delete. In Margi, /ə i u/ delete between consonants, while /a/ and peripheral mid vowels do not (Hoffman 1963: 39). In Rukai, /i/ deletes in unstressed syllables (Li 1973: 17); in Carib, it deletes before consonants, except a retroflex flap (Courtz 2008: 41); and in Kanakuru, it deletes in the Vnr__C context (Newman 1974: 11). In Alyawarra, /a/ may be deleted in a word-initial context preceding C or CC. However, /a/, being unstressed, is already centralized to [ʌ] in this context (as well as word-finally; Yallop 1977: 28).

Interestingly, deletion does not appear to optimize phonotactics, acting as a common diachronic source of complex consonant clusters (Easterday 2019). In fact, in Karok, deletion occurs only in a context where it can generate a complex consonant cluster.

3. General discussion

3.1. Explaining reduction

All of the processes described above have a straightforward account in terms of articulatory reduction. It appears that any of the components that make up a vocalic gesture can undergo reduction. We find both reduction in the magnitude of gestures as well as reduction in the duration of gestures.

Lindblom (1963), Bybee *et al.* (1998), Crosswhite (2001) and Barnes (2006) all propose that decreased duration leads to reduction of articulatory actions. The actions affected involve the lips, tongue, jaw and glottis. Though quality changes in our study were restricted to unstressed syllables, the other types of changes were not, yet the vast majority of processes found in the database affect vowels in unstressed syllables. Unstressed syllables are least likely to be attended to by both the speaker and the listener, and therefore are least subject to selection pressures that are driven by factors other than articulatory streamlining, discussed in section 1.1. At the same time, the reduced duration of unstressed syllables leaves less time for the displacement of the articulators, leading to reduction (Lindblom 1963). As expected, we found no voicing of voiceless vowels, addition of lip rounding or lengthening reported for vowels in unstressed syllables.

The quality changes found in the survey typically move vowels to a mid-central position. There are no lowering processes that take a vowel lower than mid and no backing or fronting beyond the central position. Raising, though much less common, is less constrained, as low vowels can become mid and mid vowels high. Lingual gestures govern the front-back dimension and if these gestures are reduced so that the tongue does not move quite so far forward or backward, centralization results. Vowel height is governed by both the tongue body and the jaw, which may explain why both raising and lowering are found in unstressed vowels. Lowering of high vowels could result from a reduction of the tongue body raising gesture and/or the reduction of the jaw raising gesture. Lowering beyond the mid level is not expected, because that would require extra gestural magnitude to lower the jaw and tongue body. Similarly, raising of low vowels is attributable to a reduction of tongue-body lowering and/or jaw lowering.

Our survey of phonetic processes did not turn up cases of raising of unstressed mid vowels to high vowels, though such phonetic changes do occur, e.g. in Brazilian Portuguese (Major 1985). These would appear to contradict the directionality of reduction predicted by the articulatory approach unless we take into account the jaw position for surrounding consonants, which is usually high. The reduction of mid vowels to high can then be explained as a failure to lower the jaw to the mid position, which would allow the reduced vowels to have a relatively higher tongue position.

The AlloPhon survey, which showed vowel quality reduction on the front-back dimension to be more prominent than reduction on the height dimension, contrasts with the surveys of neutralizing vowel quality changes in Crosswhite (2001) and Barnes (2006), who consider neutralization on the height dimension to be the major phonological type. The main reason is likely the choice of language sample, as Crosswhite and Barnes have focused on Romance and Slavic languages, while our survey is intended to be more representative of the languages of the world.

Crosswhite (2001, 2004) and Harris (2005) propose two major types of vowel reduction patterns. Their proposals are intended to offer an explanation for neutralization types and are formulated in terms of perceptual optimality. Harris' proposal is that one type of vowel reduction moves vowels to the periphery, producing some version of the vowels /i u a/. However, we do not observe changes that make vowels in weak positions more peripheral, a result we replicated in another database, P-Base (Mielke 2008). Instead, we observe only raising and centralization, which are consistent with articulatory reduction.

A fundamental difference between the usage-based approach and those of Crosswhite and Harris is that a usage-based approach seeks to understand how systems emerge by the mechanistic operation of processes that are motivated in their own right, not directed towards some goal. That is, vowel reduction is not motivated by 'desires' as Crosswhite proposes – "desire to avoid loud and lengthy vowel qualities in unstressed position" (p. 34) or "desire for vowels to be well spaced out" (p. 111). Rather, reduction results from automatization, a process that affects all repeated neuro-motor behavior.

3.2. The nature of automatization

With practice, articulatory sequences become more efficient. Here we have been concerned only with the reduction of actions, but this is not the only way to increase efficiency. Overlap of gestures is also an important factor and often leads to assimilatory sound changes (see also Krasovitsky *this issue*). Furthermore, it is not necessarily the case that a shorter distance traveled is always the most efficient (Pouplier 2012). To illustrate this, consider an experimental study of automatization, in which Sosnik *et al.* (2004) asked participants to repeatedly draw a line through a series of dots, traversing the dots in a fixed order. Inexperienced participants slowed down at each target location to change direction. In contrast, practiced participants planned one smooth movement trajectory that rapidly passed through all of the dots without slowing down. Sosnik and colleagues argued that one hallmark of expertise is the smoothness of the velocity profile of the moving articulators: the more of an expert one is, the less one needs to slow down midway through an action sequence. The expert in Figure 1 actually traverses a longer distance than the novice, but the increased distance allows the expert not to slow down at individual targets.

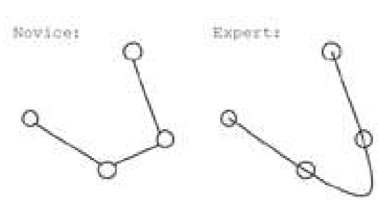

Figure 1. An expert smoothly traverses all targets without slowing down or dramatically changing direction.

When we understand movement optimization better, we may also be able to see other kinds of sound changes as due to automatization. For example, diphthongization of long vowels may be more efficient than holding the tongue in a fixed position throughout the vowel, as the former produces a smoother velocity profile. Another possible example of this type of automatization is glide strengthening, the dominant type of consonant change that increases the degree of constriction of a consonant (Bybee & Easterday 2019). Palatal glide strengthening, which yields a fricative or affricate, could be the result of the movement trajectory of a glide before a vowel extending past the target, as in Figure 1. The decrease in velocity that occurs at the point of maximal curvature can lead to the creation of frication. Labial glides also strengthen, perhaps by the same mechanism, with one or both articulators extending their path beyond the target.

3.3. Social selection and other types of changes in sounds

Vowel reduction is hard for children (Redford 2015) but common in language change. In contrast, the opposite holds for 'major place consonant harmony' – pronouncing *take* as something that resembles *cake* to an adult listener. This is a pattern that has not been phonologized in any language (Drachman 1978; Foulkes & Vihman 2015). Yet, every child that starts attempting words like *take* early enough must produce 'consonant harmony' because the blade and body of the tongue are not under independent control early in development (Gibbon 1999). This double dissociation illustrates the power of social selection in language change. Childlike consonant harmony patterns do not survive social selection to become part of the community grammar, whereas adult vowel reduction patterns do. With the exception of situations in which the adult speech community has not settled on stable norms (Hudson Kam & Newport 2005), a young child is imitated only in jest, preventing child innovations from spreading (see also Romaine 1989).

Some changes in sounds are driven by social selection rather than automatization of production. While relatively low in acoustic salience, vowel reduction processes are also not immune from becoming socially marked (e.g. Delforge 2012). Once alternative pronunciation variants are associated with distinctive uses – whether social, lexical, or both – articulatory ease is no longer free to determine pronunciation. Thus, a sound change can be stopped if the innovative and/or conservative pronunciation variant becomes associated with particular lexical or social contexts, resulting in stable variation.

Changes due to articulatory automatization are phonetically gradual and similar across languages. Changes due to social selection are phonetically arbitrary and can be unique. Rarely, an articulatorily-motivated change may reverse if the social meaning with which the innovative variant has become associated is not one that speakers wish to express, or are reinforced for expressing. For example, Delforge (2012) demonstrates that vowel devoicing in Cusco Spanish has begun to disappear in younger speakers, having acquired negative social connotations. The voicing of devoiced vowels is crosslinguistically rare. As this case shows, its occurrence is due to social, not phonetic factors.

The primary motivation for a change can often be gleaned from the way it diffuses through the lexicon (Bybee 2012). Automatization must affect frequent words first. Changes that affect infrequent words first may instead be caused by misperception or imperfect transmission. Well-documented recent examples of such changes include the spread of standard pronunciations through the Netherlands (Wieling *et al.* 2011), and chain shifts affecting stressed vowels in New Zealand English (Hay *et al.* 2015).

4. Conclusion

A usage-based approach to sound change and the phonological patterns that result from it encourages us to examine the many factors that contribute to the phonetic aspects of a usage-event. Focusing on vowel reduction, in the foregoing we have tried to identify some of the neuromotor, cognitive and social factors that facilitate or constrain vowel reduction. In addition, we have contributed a crosslinguistic study of vowel reduction that gives us a framework for further research into the universal phonetic factors that govern vowel reduction and the automatization of production in general.

Notes

1 We use slanted brackets to indicate the phonemic representation of the vowel assigned by the author of the grammar and square brackets to indicate the phonetic symbol used for the contextual variant.

Bibliographical References

Allen, George D. & Hawkins, Sarah 1978. The development of phonological rhythm. In Bell, Alan & Bybee Hooper, Joan (eds.), *Syllables and segments*. New York: North-Holland Publishing. 173-185.

Anceaux, Johannes C. 1965. *The Nimboran Language: Phonology and Morphology*. The Hague: Nijhoff.

Barnes, Jonathan 2006. *Strength and Weakness at the Interface: Positional Neutralization in Phonetics and Phonology*. Berlin: de Gruyter.

Barnes, Jonathan 2007. Phonetics and phonology in Russian unstressed vowel reduction: A study in hyperarticulation. Manuscript, Boston University.

Barth-Weingarten, Dagmar & Couper-Kuhlen, Elizabeth 2011. Action, prosody and emergent constructions: The case of *and*. In Auer, Peter & Pfänder, Stefan (eds.), *Constructions: Emerging and emergent*. Berlin: de Gruyter. 263-292.

Bell, Alan; Jurafsky, Daniel; Fosler-Lussier, Eric; Girand, Cynthia; Gregory, Michelle & Gildea, Daniel 2003. Effects of disfluencies, predictability, and utterance position on word form variation in English conversation. *Journal of the Acoustical Society of America* 113. 1001-1024.

Benton, Richard A. 1971. *Pangasinan Reference Grammar*. Honolulu: University of Hawaii Press.

Black, K. & Black, K. 1971. *The Moro Language Grammar and Dictionary*. Khartoum: Sudan Research Unit, Faculty of Arts.

Braine, Jean Critchfield 1970. *Nicobarese grammar (Car dialect)*. PhD dissertation. University of California, Berkeley.

Bright, William 1957. *The Karok Language*. Berkeley: University of California.

Brok, O. 1916. *Govory k Zapadu ot Mosal'ska* [Dialects to the west of Mosal'sk]. Petrograd.

Browman, Catherine & Goldstein, Louis 1992. Articulatory Phonology: An overview. *Phonetica* 49. 155-180.

Brown, Esther L. 2018. Cumulative exposure to phonetic reducing environments marks the lexicon. In Smith, K. Aaron & Nordquist, Dawn (eds.), *Functionalist and usage-based approaches to the study of language*. Amsterdam: John Benjamins. 127-153.

Bryan, William L. & Harter, Noble 1897. Studies in the physiology and psychology of the telegraphic language. *Psychological Review* 4. 27-53.

Buz, Esteban; Tanenhaus, Michael K. & Jaeger, T. Florian 2016. Dynamically adapted context-specific hyper-articulation: Feedback from interlocutors affects speakers' subsequent pronunciations. *Journal of Memory and Language* 89. 68-86.

Bybee, Joan 1985. *Morphology: A Study of the Relation between Meaning and Form*. Amsterdam: John Benjamins.

Bybee, Joan 2002. Word frequency and context of use in the lexical diffusion of phonetically-conditioned sound change. *Language Variation and Change* 14. 261-290.

Bybee, Joan 2010. *Language, Usage and Cognition*. Cambridge: Cambridge University Press.

Bybee, Joan 2012. Patterns of lexical diffusion and articulatory motivation for sound change. In Solé, Maria-Josep & Recasens, Daniel (eds.), *The Initiation of Sound Change: Perception, Production and Social Factors*. Amsterdam: John Benjamins. 211-234.

Bybee, Joan 2015. *Language change.* Cambridge: Cambridge University Press.

Bybee, Joan; Chakraborti, Paromita; Jung, Dagmar & Scheibman, Joanne 1998. Prosody and segmental effect: some paths of evolution for word stress. *Studies in Language* 22. 267-314.

Bybee, Joan; Perkins, Revere & Pagliuca, William 1994. *The Evolution of Grammar: Tense, Aspect and Modality in the Languages of the World.* Chicago: University of Chicago Press.

Bybee, Joan & Easterday, Shelece 2019. Consonant strengthening: a crosslinguistic survey and articulatory proposal. *Linguistic Typology* 23. 263-302.

Bybee, Joan; File-Muriel, Richard & Napoleão de Souza, Ricardo 2016. Special reduction: A usage-based approach. *Language and Cognition* 8. 421-446.

Chen, Ajou 2011. Tuning information packaging: Intonational realization of topic and focus in child Dutch. *Journal of Child Language* 38. 1055-1083.

Courtz, Henk 2008. *A Carib Grammar and Dictionary*. Toronto: Magoria Books.

Crosswhite, Katherine 2001. *Vowel Reduction in Optimality Theory.* New York & London: Routledge.

de Jong, Kenneth J. 1995. The supraglottal articulation of prominence in English: Linguistic stress as localized hyperarticulation. *Journal of the Acoustical Society of America* 97. 491-504.

Delforge, Ann Marie 2012. 'Nobody wants to sound like a provinciano': The recession of unstressed vowel devoicing in the Spanish of Cusco, Perú. *Journal of Sociolinguistics* 16. 311-335.

DuBois, John W. 1981. *The Sacapultec Language*. Ann Arbor: University of Michigan.

Easterday, Shelece 2019. *Highly complex syllable structure: a typological and diachronic study*. Berlin: Language Science Press.

Faust, Norma & Pike, Evelyn G. 1959. *The Cocama Sound System – O Sistema Fonêmico do Kokama*. Rio de Janeiro: Publicações do Museu Nacional. 10-55.

Foley, William A. 1991. *The Yimas Language of Papua New Guinea*. Stanford: Stanford University Press.

Foulkes, Paul & Vihman, Marilyn 2015. First language acquisition and phonological change. In Honeybone, Patrick & Salmons, Joseph (eds.), *The Oxford handbook of historical phonology*. Oxford: Oxford University Press. 289-312.

Fowler, Carol A.; Levy, Elena T. & Brown, Julie M. 1997. Reductions of spoken words in certain discourse contexts. *Journal of Memory and Language* 37. 24-40.

Frantz, Donald G. 1972. Cheyenne distinctive features and phonological rules. *International Journal of American Linguistics* 38. 6-13.

Furbee-Losee, Louanna 1976. *The Correct Language: Tojolabal: A Grammar with Ethnographic Notes*. New York: Garland.

Gibbon, Fiona E. 1999. Undifferentiated lingual gestures in children with articulation / phonological disorders. *Journal of Speech, Language, and Hearing Research* 42. 382-397.

Goffman, Lisa 2004. Kinematic differentiation of prosodic categories in normal and disordered language development. *Journal of Speech, Language, and*

Hearing Research 47. 1088-1102.
Goldstein, Michael H.; King, Andrew P. & West, Meredith J. 2003. Social interaction shapes babbling: Testing parallels between birdsong and speech. *Proceedings of the National Academy of Sciences* 100. 8030-8035.
Gordon, Matthew 1998. The phonetics and phonology of non-modal vowels: A crosslinguistic perspective. *Berkeley Linguistics Society* 24. 93-105.
Greenberg, Joseph H. 1969. Some methods of dynamic comparison in linguistics. In Puhvel, Jaan (ed.), *Substance and structure of language*. Los Angeles: Center for Research in Languages and Linguistics. 147-204.
Hale, Kenneth L. 1959. *A Papago grammar*. PhD dissertation. Indiana University, Bloomington.
Hay, Jennifer & Foulkes, Paul 2016. The evolution of medial /t/ over real and remembered time. *Language* 92. 298-330.
Hay, Jennifer B.; Pierrehumbert, Janet B.; Walker, Abby J. & LaShell, Patrick 2015. Tracking word frequency effects through 130 years of sound change. *Cognition* 139. 83-91.
Hayami-Allen, Rika 2001. *A descriptive study of the language of Ternate, the northern Moluccas, Indonesia.* PhD dissertation. University of Pittsburgh.
Hefferman, Kevin 2010. Mumbling is macho: Phonetic distinctiveness in the speech of American radio DJs. *American Speech* 85. 67-90.
Hoffman, Carl 1963. *A grammar of the Margi language*. London: Oxford University Press.
Holt, Dennis 1999. *Pech (Paya)*. München: Lincom Europa.
Hooper, Joan Bybee 1976. Word frequency in lexical diffusion and the source of morphophonological change. In Christie, William (ed.), *Current progress in historical linguistics*. Amsterdam: North Holland. 96-105.
Householder, Fred W.; Kazasis, Kostas & Koutsoudas, Andreas. 1964. *Reference Grammar of Literary Dhimotiki.* Bloomington: Indiana University.
Hudson Kam, Carla L. & Newport, Elissa L. 2005. Regularizing unpredictable variation: The roles of adult and child learners in language formation and change. *Language Learning and Development* 1. 151-195.
Jacq, Pascale & Sidwell, Paul 1999. *Sapuan (Sepuar)*. München: Lincom Europa.
Jaeger, Jeri J. 1978. Speech aerodynamics and phonological universals. *Berkeley Linguistics Society* 4. 311-329.
Jannedy, Stefanie 1995. Gestural phasing as an explanation for vowel devoicing in Turkish. *Ohio State University Working Papers in Linguistics* 45. 56-84.
Kapatsinski, Vsevolod 2014. Sound change and hierarchical inference: What is being inferred? Effects of words, phones and frequency. Manuscript, University of Oregon.
Kapatsinski, Vsevolod 2018. *Changing minds changing tools: From learning theory to language acquisition to language change.* Cambridge, MA: MIT Press.
Kasatkin, L. L. 2010. K istorii akan'ja-jakan'ja v russkom jazyke. *Slavica Helsingensia* 40. 17-31.
Knjazev, S. V. 2004. Zvukovye izmenenija v russkom i praslavjanskom jazykax v svete sovremennyx fonetičeskix predstavlenij. *Vestnik Moskovskogo Universiteta, Filologija* 2. 9-33.
Krasovitsky, Alexander *this issue*. Vowel reduction in a North Russian dialect: A case study. *Italian Journal of Linguistics* 32.
Labov, William 2006. A sociolinguistic perspective on sociophonetic research.

Journal of Phonetics 34. 500-515.
Li, Paul Jen-Kuei 1973. *Rukai structure.* PhD dissertation. University of Hawaii, Mānoa.
Lichtenberk, Frantisek 2008. *A Grammar of Toqabaqita*. Berlin: de Gruyter.
Lightfoot, David 1999. *The Development of Language: Acquisition, Change, and Evolution*. Oxford: Blackwell.
Lindblom, Björn 1963. Spectrographic study of vowel reduction. *Journal of the Acoustical Society of America* 35. 1773-1781.
Lindblom, Björn 1990. Explaining phonetic variation: A sketch of the H&H theory. In Hardcastle, William J. & Marchal, Alain (eds.), *Speech production and speech modelling*. Dordrecht: Springer. 403-439.
Lininger, Ross B. 1981. Estudios sobre el Guaymí Ngäbere: Fonología, alfabeto y diccionario provisional. *Revista de Filología y Lingüística de la Universidad de Costa Rica* 7. 101-115.
Major, Roy C. 1985. Stress and rhythm in Brazilian Portuguese. *Language* 61. 259-282.
Manning, Margaret & Saggers, Naomi 1977. A tentative phonemic analysis of Ningil. In Loving, Richard (ed.), *Phonologies of five Papua New Guinea languages*. Ukarumpa, Papua New Guinea: Summer Institute of Linguistics. 49-72.
McElhanon, Kenneth A. 1970. *Selepet Phonology*. Canberra: Australian National University.
Mielke, Jeff 2008. *The Emergence of Distinctive Features*. Oxford: Oxford University Press.
Mowrey, Richard & Pagliuca, William 1995. The reductive character of articulatory evolution. *Rivista di Linguistica* 7. 37-124.
Newman, Paul 1974. *The Kanakuru Language*. Leeds: University of Leeds.
Newman, Stanley 1965. *Zuni Grammar*. Albuquerque: University of New Mexico Press.
Ohala, John J. 1983. The origin of sound patterns in vocal tract constraints. In Peter F. MacNeilage (ed.), *The production of speech*. New York: Springer. 189-216.
Platt, John T. 1972. *An Outline Grammar of the Gugada Dialect, South Australia.* Canberra: Australian Institute of Aboriginal Studies.
Pollock, Karen E.; Brammer, Diane M. & Hageman, Carlin F. 1993. An acoustic analysis of young children's productions of word stress. *Journal of Phonetics* 21. 183-203.
Pouplier, Marianne 2012. The gaits of speech: Re-examining the role of articulatory effort in spoken language. In Solé, Maria-Josep & Recasens, Daniel (eds.), *The Initiation of Sound Change: Perception, Production and Social Factors*. Amsterdam: John Benjamins. 147-164.
Prasse, Karle-G. 1972. *Manuel de grammaire Touaregue (tahaggart), parts 1-3: Phonétique, écriture, pronom*. Copenhagen: Editions de l'Université de Copenhague.
Redford, Melissa A. 2015. The acquisition of temporal patterns. In Redford, Melissa A. (ed.), *The handbook of speech production.* Malden: Wiley. 379-403.
Redford, Melissa A. & Gildersleeve-Neumann, Christina E. 2009. The development of distinct speaking styles in preschool children. *Journal of Speech, Language, and Hearing Research* 52. 1434-1448.
Redford, Melissa A.; Kapatsinski, Vsevolod & Cornell-Fabiano, Jolynn 2018. Lay listener classification and evaluation of typical and atypical children's

speech. *Language and Speech* 61. 277-302.

Romaine, Suzanne 1989. The role of children in linguistic change. In Breivin, Leiv E. & Jahr, Ernst H. (eds.), *Language change: Contributions to the study of its causes*. Berlin: de Gruyter. 199-226.

Ross, Malcolm 2002. Taiof. In Lynch, John; Ross, Malcolm & Crowley, Terry (eds.), *The Oceanic language*. Richmond, UK: Curzon Press. 426-439.

Sandalo, Filomena 1997. A grammar of Kadiweu: With special reference to the polysynthesis parameter. *MIT Working Papers in Linguistics* 11.

Seyfarth, Scott 2014. Word informativity influences acoustic duration: Effects of contextual predictability on lexical representation. *Cognition* 133. 140-155.

Shipley, William F. 1964. *Maidu Grammar*. Berkeley: University of California Press.

Skinner, B. F. 1981. Selection by consequences. *Science* 213. 501-504.

Sóskuthy, Márton & Hay, Jennifer 2017. Changing word usage predicts changing word durations in New Zealand English. *Cognition* 166. 298-313.

Sosnik, Ronen; Hauptmann, Bjoern; Karni, Avi & Flash, Tamar 2004. When practice leads to co-articulation: The evolution of geometrically defined movement primitives. *Experimental Brain Research* 156. 422-438.

Steriade, Donca 2001. Directional asymmetries in place assimilation: A perceptual account. In Hume, Elizabeth & Johnson, Keith (eds.), *The role of speech perception in phonology*. San Diego: Academic Press. 219-250.

Sutton, Richard S. & Barto, Andrew G. 1998. *Reinforcement Learning: An Introduction*. Cambridge, MA: MIT Press.

Taylor, Douglas 1955. Phonemes of the Hopkins (British Honduras) dialect of Island Carib. *International Journal of American Linguistics* 21. 233-241.

Tomaschek, Fabian; Tucker, Benjamin V. & Baayen, R. Harald 2018. How is anticipatory coarticulation of suffixes affected by practice? Manuscript, University of Tuebingen and University of Alberta.

Tomaschek, Fabian; Wieling, Martijn; Arnold, Dennis & Baayen, R. Harald 2013. Word frequency, vowel length and vowel quality in speech production: An EMA study of the importance of experience. *Proceedings of Interspeech 2013*. 1302-1306.

Turner, Glen D. 1958. *Jivaro: Phonology and morphology*. PhD dissertation. Indiana University, Bloomington.

Vajrabhaya, Prakaiwan 2015. *Cross-modal reduction: Repetition of words and gestures*. PhD dissertation. University of Oregon, Eugene.

Van Bergem, Dick 1995. *Acoustic and Lexical Vowel Reduction*. Amsterdam: IFOTT.

Van der Leeden, Alex C. 1993. *Ma'ya: A Language Study. Phonology*. Jakarta: Lembaga Ilmu Pengetahuan Indonesia and Rijksuniversiteit te Leiden.

Warlaumont, Anne S.; Richards, Jeffrey A.; Gilkerson, Jill & Oller, D. Kimbrough 2014. A social feedback loop for speech development and its reduction in autism. *Psychological Science* 25. 1314-1324.

Wieling, Martijn; Nerbonne, John & Baayen, R. Harald 2011. Quantitative social dialectology: Explaining linguistic variation geographically and socially. *PloS One* 6. e23613.

Yallop, Colin 1977. *Alyawarra: An Aboriginal Language of Central Australia*. Canberra: Australian Institute of Aboriginal Studies.

Appendix

Languages in AlloPhon with phonetic vowel reduction processes as defined in this study.

Language (Family)	PHONETIC VOWEL REDUCTION PROCESSES
Alyawarra *(Pama-Nyungan)*	/a/ becomes raised and backed [ɐ] or [ʌ] word-initially and word-finally (which are unstressed). /a/ may be deleted in a #_(C)C environment, which is pretonic. Short vowels delete before sonorant consonants.
Carib *(Cariban)*	/i/ deletes before consonants, except for retroflex flaps. Unstressed vowels delete word-initially in the second word of a compound. Unstressed vowels delete word-finally before a vowel.
Cheyenne *(Algic)*	Unaccented vowels become voiceless in six different environments.
Cocama *(Tupian)*	Vowels may become voiceless word-initially. Vowels may become voiceless when unstressed.
Guaymí *(Chibchan)*	Vowels may be realized as [ə] in unstressed syllables. Unstressed vowels may variably delete.
Gugada *(Pama-Nyungan)*	Vowels may reduce to [ə] in the syllable following the initial stressed syllable. /ɑ/ may be realized as [ʌ] word-finally.
Island Carib *(Arawakan)*	Vowels are laxer in unstressed syllables between consonants. /i/ is shorter, laxer, and partly devoiced when unstressed and between consonants.
Jivaro *(Chicham)*	Unstressed vowels are devoiced or deleted between voiceless consonants word-medially. Voiceless vowels elide in a ‘final contour’.
Kadiwéu *(Guaicuruan)*	/ɛ ɛː/ are realized as [e] in word-final position, which is unstressed. Long vowels are shortened preceding a voiceless stop.
Kanakuru *(Afro-Asiatic)*	/i/ deletes in the environment of Vnr_C in rapid speech.
Karok *(isolate)*	/a/ > [ə] when unaccented. Short vowels are whispered in a post-tonic syllable preceding a pause. Long vowels become glottalized post-tonically before a pause. Short vowels delete in #_CC environment.
Ma’ya *(Austronesian)*	Vowels with 2-1 tone become shortened sentence-finally.
Maidu *(Maiduan)*	Vowels centralize in unstressed syllables in ‘allegro’ speech.
Margi *(Afro-Asiatic)*	/ə i u/ delete between consonants.

Quality change	Shortening	Devoicing	Deletion
✓			✓
			✓
		✓	
		✓	
✓			✓
✓			
✓	✓	✓	
		✓	✓
✓	✓		
			✓
✓		✓	✓
	✓		
✓			
			✓

Modern Greek *(Indo-European)*	In rapid speech, unstressed vowels become voiceless after a voiceless consonant and before a pause.
Moro *(Heibanic)*	/i a/ are realized as [ɪ ɐ] in the unstressed word-initial environment.
Nicobarese *(Austroasiatic)*	Vowels become very short preceding a syllable-final /h/.
Nimboran *(Nimboranic)*	/a/ is realized as mid open before a consonant followed by an accented vowel. Unstressed /o/ is unrounded word-finally.
Ningil *(Nuclear Torricelli)*	/ɨ/ are sporadically realized as [ə] in unstressed syllables.
Pangasinan *(Austronesian)*	/i u a/ are realized as [ɪ ʊ ə] in unstressed syllables.
Pech *(Chibchan)*	Short vowels become open and lax in unstressed, closed syllables. In rapid speech, /i/ is sometimes realized as [ə]. Long vowels shorten in unstressed open syllables. Unstressed vowels are deleted between stressed syllables. Unstressed vowels are deleted in the C_r environment.
Rukai *(Austronesian)*	/i/ is deleted in unstressed syllables.
Sapuan *(Austroasiatic)*	Vowels are shortened before glottal consonants.
Selepet *(Nuclear Trans New Guinea)*	Vowels become shorter in a pretonic position. Vowels may delete in a posttonic position.
Ternatean *(North Halmahera)*	/o/ is raised to [u] in antepenultimate (pretonic) position. Unstressed vowels may delete in fast speech.
Tohono O'odham *(Uto-Aztecan)*	Many devoicing processes affect vowels, with some processes limited to specific (e.g. high, long, or stressed) subsets of vowels).
Tojolabal *(Mayan)*	Vowels become partially voiceless utterance-finally.
Toqabaqita *(Austronesian)*	Unstressed vowels variably become voiceless word-finally and between voiceless consonants.
Uighur *(Turkic)*	High vowels become voiceless between voiceless consonants.
West Greenlandic *(Eskimo-Aleut)*	Short high vowels become voiceless in open syllable between voiceless consonants.
Yimas *(Lower Sepik-Ramu)*	/a/ is realized as [ʌ] when unstressed.
Zuni *(isolate)*	/i u/ are sporadically realized as [ɪ ʊ] in unstressed syllables.

		✓	
✓			
	✓		
✓			
✓			
✓			
✓	✓		✓
			✓
	✓		
	✓		✓
✓			✓
		✓	
		✓	
		✓	
		✓	
		✓	
✓			
✓			