A Survey of Experimental Evidence for Diachronic Change

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Abstract

There are synchronic sources of data that can provide an additional line of evidence which may be useful in reconstructing sound changes: patterns of sound change in progress and experimentally induced changes, variation in production, natural errors in production and perception, experimentally elicited errors in perception and production, and experiments and simulations of iterated learning. This article surveys existing studies that have made use of such evidence in support of sound changes and reviews limitations of experimental methods and factors to consider when designing experiments to use these parallels to inform sound change.

To demonstrate the parallels between patterns in synchronic data and sound changes, a sample typology of diachronic developments was compared with patterns of categorical errors from experimentally elicited misperception in adverse listening conditions and natural errors in perception and production. All of these correlations are highly significant, demonstrating the potential of such synchronic data as a source of parallels to provide evidence for reconstructed sound changes.

1 Introduction

An important source of information for sound change is synchronic data: articulation, aerodynamics, acoustics, and patterns of perception and allophonic alternations (Ohala 1974; Yu 2015). Connections between synchronic and diachronic data can be attributed to biases in perception and production (Yu 2015: 415–422) and explained with theoretical phonology (Kiparsky 2008), but moreover can be tested experimentally, as was already noted in early work (e.g. Haden 1938; Rousselot 1901–1908) and more actively pursued in later research, as presented in sections 2.3 and 3.3. I will present a survey of experimental methods that can inform reconstruction; I do not aim to explain why change occurs, but rather to demonstrate testable parallels.

Patterns in production can demonstrate biases resulting from motor planning, gestural mechanics, and aerodynamics (Garrett and Johnson 2013: 58–63; Stuart-Smith 2004: 160–194). Existing variability in production makes it possible for speakers to gradually shift their productions, or for listeners to reanalyze the target (Paul 1886: 50–60; Baudouin de Courtenay 1972[1895]: 198–208; Blevins 2004: 7–8).

Perception is also a potential source of change; acoustic similarity facilitates misperception and subsequently change (Sweet 1874: 15–17; Ohala 1993b: 241–243). If a sound change has phonetic grounding, it should be possible to find a parallel in perception or production, as long as the conditions can be replicated (Ohala 1993a, Ohala 1993b, a.o.). While it has been suggested that errors reflected in language acquisition are in part responsible for sound change (e.g. Paul 1886: 51–52; Grammont 1933: 175–179), later work finds that patterns of child phonology do not present parallels to sound change beyond those which are provided by adult phonological patterns (Foulkes and Vihman 2015: 301–311; Greenlee and Ohala 1980: 286–289).

2 Production
2.1 Variability in production

There is naturally occurring variability in production, which provides a clear parallel for diachronic developments and has often been presented as a source of potential sound changes.

The utterances made by a speaker exhibit variability based on phonological environment, morphology, and lexical information, in addition to statistical distributions within those conditions, e.g. final t/d deletion in English (Coetzee and Pater 2011) and effects of the speaking environment and listener (Lindblom 1990). There is also variation within a community due to factors like register and demographic categories like age, gender, and social class (Anttila 2007: 534–535).

Much of this variability comes from the combinations of gestures in speech. Neighboring gestures produced with the same articulator can produce different degrees of partial assimilation, and variation in the overlap of gestures from different articulators can result in additional types of change, e.g. excrescent stops in nasal-fricative sequences (Browman and Goldstein 1991: 324–327). Productions can also vary by syllable position; onset consonants overlap with vowels more than coda consonants do and tend to have more extreme articulator positions (Browman and Goldstein 1995; Marin and Pouplier 2010).

There is also variation due to aerodynamic constraints that make certain combinations of articulator positions and glottal postures difficult to maintain: e.g. the pressure difference needed to maintain voicing in obstruents (Ohala 1997; Garrett and Johnson 2013: 62).

2.2 Production errors

Mispronunciations provide a different source of evidence for aspects of pronunciation that may influence sound changes. Early collections of such errors – productions recognized by the speaker and listener as not belonging to the intended category – in natural speech were made by Meringer (1908) and Meringer and Mayer (1895) within German. Similar collections have been made by Fromkin (1971) and Shattuck-Hufnagel and Klatt (1979) in English and by van den Broecke and Goldstein (1980) in English, Dutch, and German. Mowrey and MacKay (1990) elicited similar errors using tongue twisters.

Such errors have been interpreted as evidence for phonological categorization and motor planning (van den Broecke and Goldstein 1980; Shattuck-Hufnagel and Klatt 1979), and may provide a line of evidence for the confusability of segments. While sound changes are generally not attributed to such production errors, they may reflect similar processes; some patterns in speech errors have diachronic parallels (Garrett and Johnson 2013: 65–67).

In production errors, the intended sound and produced sound are usually phonologically similar (Shattuck-Hufnagel and Klatt 1979; Levitt and Healy 1985). The beginnings of the target word and produced word are particularly likely to be similar (Fay and Cutler 1977: 514–16), though in many collections of speech errors, errors are

most frequent in initial position (van den Broecke and Goldstein 1980: 48), perhaps because the importance of this position in lexical access makes such errors more conspicuous (Cutler 1981: 574). It is likely that many production errors in natural speech go unnoticed (Cutler 1981: 569–570); when mispronunciations are presented to listeners in a repetition task, listeners often produce the target word without the mispronunciation (Marslen-Wilson and Welsh 1978; Bond and Small 1983).

2.3 Experimental connections between production and sound change

Some descriptions of sound changes posit possible articulatory pathways for the changes, and may include measurements of variation in modern languages to demonstrate the existence of the proposed articulatory effect. This overview focuses on studies based on acoustic or articulatory data.

Early work on modern parallels for diachronic developments were in allophonic patterns and internal variation, e.g. Delattre's (1946) comparison between changes in Old French and patterns of allophones and changes in modern Spanish dialects. The similarity of their phonological systems, morphology, and lexicons produce a much closer parallel than would be provided by comparison of two unrelated languages.

Hombert et al. (1979) provide evidence for a pathway of tonogenesis conditioned by obstruent voicing, which is reconstructed independently in several different language families. They demonstrate that f0 is significantly higher next to voiceless stops than next to voiced stops.

Recasens (2012) uses acoustic and articulatory data in productions of /ɬ/ as evidence for an articulation-based pathway for the development of /ɬ/ to /w/, which is observed in several Romance languages and elsewhere. Undershoot or late occurrence of the apical gesture in /ɬ/ produces an approximant similar to /w/; the F2 lowering associated with the dorsal gesture may have become the primary cue for identification, particularly next to noncoronals, where the apical gesture is reduced or obscured.

The conditioning environments for diachronic VN > Ṽ changes are paralleled by environments that produce perceptually ambiguous nasality patterns (Beddor 2009: 813–817; Beddor et al. 2007: 141). VN > Ṽ changes are observed more frequently when the following obstruent is voiceless than when it is voiced (Hajek 1997: 141–142); nasalization on the vowel in VNC sequences is longer when the consonant is voiceless than when it is voiced (Beddor et al. 2007: 140–141). VN > V Ṽ is also more likely before fricatives (Hajek 1997: 143–144), which is paralleled by shorter duration of nasals preceding fricatives (Beddor et al. 2007: 142).

Solé (2007) presents experimental data demonstrating the articulatory and aerodynamic patterns in sequences of fricative + nasal. Such sequences diachronically often end up either losing the fricative or developing a stop between the fricative and the nasal. Solé's production data neatly aligns with these two patterns: these sequences are often produced either with late lowering of the velum, resulting in an excrescent stop, or early lowering of the velum, resulting in fricatives which are less audible due to decreased oropharyngeal pressure.

3 Perception

Listeners usually accurately compensate for predictable influences of phonological environment (Martin and Bunnell 1981; Fowler et al. 1990). Splicing, amplitude reduction, and other manipulations of stimuli demonstrate that the presence of the conditioning environment is crucial (Mann and Repp 1980; Kawasaki 1986; Beddor 2009).

However, listeners do not always accurately perceive utterances and analyze the underlying form as intended by the speaker. Under the listener-driven model of sound change, change is hypothesized to result from the spread of such listener errors, so data on these errors can inform reconstruction (Ohala 2003: 673–677; Browman and Goldstein 1991: 328–333; see also Ohala 1981, 1993a, a.o.).

3.1 Misperception experiments

Patterns of misperception provide a line of evidence for sound changes, though the experimental conditions necessary to obtain misperceptions make this data somewhat distinct from the misperceptions that might lead to sound changes. Important factors of experimental design are discussed in the following sections.

There are many studies on patterns of misperception of segments, following the seminal work by Miller and Nicely (1955) on consonants and Pickett (1957) on vowels, but most of them are not meant as evidence for sound change. Most perception studies are on consonants, so that is the focus in the following discussion.

3.1.1 Influences of language of the experiment

The majority of misperception studies have been conducted with English stimuli and English listeners, so misperception data is limited by biases particular to English, which must be considered in any comparison. Some perception studies have been conducted on other languages, e.g. French (Meyer et al. 2013); Dutch (Verschuure and Brocar 1983); Hindi, English, Arabic, and Japanese (Singh and Black 1966). Singh and Black show that misperception patterns can differ among groups with different native languages, even for sounds which have analogues in all of the languages.

Responses depend on phonological inventory and are biased by it even if listeners are trained in new symbols to indicate foreign sounds (Singh and Black 1966). There is also an effect of phoneme frequency on decisions, particularly in challenging listening conditions with low overall accuracy (Sanker 2016a: 285–287).

Lexical and phonotactic knowledge from a listener's language can also influence decisions, particularly when the stimulus is ambiguous or unclear. Listeners more frequently give responses of real words than non-words (Ganong 1980), as well as more often selecting words with frequently occurring subparts (Plauché 2001: 170–171).

3.1.2 Effects of phonological context

Misperception studies have also demonstrated a range of influences of phonological environment. These effects can restrict what diachronic comparisons will be informative. The phonological environments within an experiment should match the

environment of a sound change which the data is meant to inform; unconditioned sound changes should be paralleled in experimental results across a range of environments.

The accuracy of consonant identification depends on the position of the consonant within the syllable. Identification of onset consonants is generally more accurate than identification of coda consonants (Redford and Diehl 1999; Dubno and Levitt 1981; Miller and Nicely 1955), though not in all studies (Cutler et al. 2004). The influence of position varies by consonant (Ohde and Sharf 1977; Redford and Diehl 1999) and interacts with effects of the neighboring vowel (Helfer and Huntley 1991; Wang and Bilger 1973).

Neighboring segments influence patterns of errors in consonant identifications, as has been observed for vowel environments (Redford and Diehl 1999; Dubno and Levitt 1981), though the effects are not consistent across studies. Most consonant perception studies look only at vocalic environments, so there is a dearth of data on effects of consonantal environments. Phonological environment can also influence production (Redford and Diehl 1999), so context of elicitation must be considered in order to distinguish between patterns of perception and production.

3.1.3 Masking noise and other adverse listening conditions

The particular listening conditions can influence patterns of misperception. Most misperception studies use masking noise to obtain a larger number of errors than would be present in normal listening conditions. Instead of masking noise, some studies use low stimulus intensity (e.g. Kishon-Rabin and Rosenhouse 2000), distractor tasks (e.g. Plauché 2001), or the challenge of hearing a mix of stimuli from different languages (Singh and Black 1966).

A range of noise types have been used, with some differences in the results, from the classic white noise (Miller and Nicely 1955; Phatak et al. 2008), to noise at the same average frequencies as speech (speech-shaped noise), steady-state or modulated (Broersma and Scharenborg 2010; Festen and Plomp 1990), or "babble" created by overlaying multiple speakers (van Engen and Bradlow 2007).

The effect of noise type varies by segment and which salient cues in the acoustic signal are obscured or still perceptible (Soli and Arabie 1979: 53–55). White noise and other aperiodic noise has the largest influence on coronal fricatives (Phatak et al. 2008). Miller and Nicely (1955) found that in white noise, voicing is most stable, while place is less stable, as are most manners of articulation.

Some types of masking noise clearly do not mimic listening conditions that are likely to frequently be encountered in natural speech. Among the commonly used masking noises, speech and speech-shaped noise probably most closely mimic natural adverse listening conditions. Few works use natural noise other than speech; Meyer et al. 2013 is one exception. It is currently unclear what kind of listening conditions provide the best parallel for diachronic data.

3.1.4 Other effects of setting and experimental design

The patterns observed depend on how responses are collected, so potential skewing resulting from task design must be considered in data analysis; some apparent

misperceptions may appear only because the perceived sound was not available as a response or because listeners were biased by expectations set up by the stimuli.

In particular, patterns of responses in forced-choice tasks depend on the competing options which listeners can choose from, which may skew the likelihood of a particular misperception. For example, listeners exhibit a relatively large number of k > t errors when stops are the only response options, but when tʃ is included as a response option, such errors are rare (Chang et al. 2001 vs. Plauché et al. 1997).

When the experiment does not constrain listeners to identifications within a particular syllable structure, they exhibit a lower overall accuracy and a range of error types not observed otherwise, including insertion, deletion, and metathesis (Meyer et al. 2013; Sanker 2015). Perception of each segment depends on the analysis of neighboring segments (Wahlen 1989).

3.2 Misperception errors in natural speech

Misperception errors have also been collected, from the seminal studies in German by Meringer (1908) and Meringer and Mayer (1895) to several more recent collections in English by Browman (1980), Bond (1999), and Labov (2010: Ch. 2). Error patterns have been interpreted as evidence for phonological processing and lexical retrieval as well as the salience of different acoustic cues (Browman 1980).

Reported misperceptions are usually constrained by the phonological inventory and phonotactics of the language being used (Bond 1999: 130–133), and tend to be real words, though patterns of error reporting likely skew the data (Browman 1980: 214).

3.3 Experimental connections between perception and sound change

For some historical changes, it seems that the pathway of change is likely to be related to acoustic similarity. Some studies describe such acoustic similarities in support of positing a pathway of sound change, and others have used synchronic patterns in perception as a parallel providing evidence for historical changes.

Ohala and Amador (1981) explain the diachronic phenomenon of spontaneous nasalization, in which vowels become nasal in words with no prior nasality, as resulting from the acoustic similarity. The glottal posture of voiceless fricatives and aspirated stops produces effects similar to nasality in neighboring vowels; listeners judge tokens of vowels taken from these environments to be more nasal than vowels taken from other non-nasal environments.

Beddor et al. (1986) provide a parallel for patterns of sound changes in which loss of nasal consonants is associated with a change in height of neighboring vowels. They demonstrate that American English listeners do not misperceive nasal vowel height when there is a condition for vowel nasalization, but do misjudge height when there isn't a conditioning environment.

Guion (1998) demonstrates the likely perceptual basis for the frequency of historical developments of k > tʃ before high vowels. Velar stops in this environment are not just acoustically similar to palatoalveolar fricatives, but were often misperceived as them when listeners presented with fast speech productions of CV sequences in noise. Chang et al. (2001) obtain similar results.

Foulkes (1997) presents an explanation of a perceptual pathway for the development of f > h next to /u/, which is observed in several language families. Identifications of stimuli of spliced fricatives and vowels demonstrated the ambiguity of vowel transition cues from /f/ and /h/ into /u/. If listeners use vowel cues rather than fricative spectra to identify fricatives, this ambiguity could produce the observed changes.

Myers and Hansen (2007) use experimental evidence to demonstrate that partially devoiced vowels are more likely to be identified as short. They use this as evidence for a possible pathway of phrase-final vowel shortening via devoicing, providing a potential parallel for the development of phonologized phrase-final shortening in Bantu languages.

4 Spread of changes

Modern data can also provide evidence for the spread of sound changes within a community (Weinreich et al. 1968: 112–14, 166–83) or within the lexicon (e.g. Bybee 2002; Labov 1994: 518–31).

4.1 Simulations of iterated learning

One of the limitations of most experimental data is that it lacks generational iteration, which is a central part of many gradual diachronic developments. Individuals can exhibit phonetic changes both on short time scales (e.g. Babel 2012; Nielsen 2011) and across their lifetimes (e.g. Harrington 2007; Sankoff and Blondeau 2007), but there are limits on how much they are likely to change.

Computer simulations of iterated learning, as presented e.g. by Kirby (2014), Wedel (2012), and Albright and Hayes (2002), provide information about generational learning that can complement experimental perception and production data.

There are also experimental examples of iterated learning with real learners, in which participants are trained in data from a novel language and then produce output that is given as the training data for the next stage of learners (e.g. Reali and Griffiths 2009; Smith and Wonnacott 2010).

4.2 Sound changes in progress

Investigating change in progress by tracking individuals over time (e.g. Sankoff and Blondeau 2007) or comparing samples of the population of different ages (e.g. Moreton and Thomas 2007) can provide direct evidence for sound change, which theoretical and computational models of change can be tested against.

Patterns of mergers in progress are one source of evidence that sound changes can be perceptually driven or perceptually driven. Being unable to hear a distinction which one produces suggests a perception-driven change (e.g. Yu 2007; Labov 1994: 363–364); being able to hear a distinction which one doesn't produce suggests a production-driven change (e.g. Warren et al. 2007).

Small-scale changes in experimental settings can also provide relevant data. Participants' patterns of production demonstrably become more similar to the voices they are hearing, e.g. in vowel characteristics (Babel 2012) and VOT (Nielsen 2011).

Listeners can also readjust their category boundaries in listening-only tasks (e.g. Kraljic and Samuel 2005).

5 Typology

There are few systematic typologies of sound changes, so most comparisons of the relative frequency of diachronic changes and experimentally elicited patterns are based on a limited sample of languages (e.g. nasalization patterns in Romance, Hajek 1997), changes which can be identified as common without systematic survey (e.g. k > tʃ, Chang et al. 2001; Guion 1998), or a specific set of sounds (e.g. postvelars, Simpson 2002).

Kümmel (2007) provides an extensive collection of diachronic developments of consonants, though this is limited to a few language families (i.e. Indo-European, Uralic, and Semitic). The UniDia project (Hamed and Flavier 2009), which aims to provide an extensive database of sound changes, is also limited in breadth of families covered. There are practical limitations to any sample, based on what languages are well described and how well established the reconstructed historical developments are (Hajek 1997: 32–35).

5.1 Use of typology in reconstruction

There is much synchronic experimental data available that can be considered in relation to sound change, even though most of it was not collected with this goal. Some works on diachronic change have noted the value of such misperception data in paralleling cross-linguistically common changes and the unidirectionality of some of them, e.g. palatalization and θ > f (Garrett and Johnson 2013: 70–72). The potential for a broader correlation not focused on a particular parallel is occasionally considered; Sanker (2016b) provides a comparison of misperception and diachronic developments of postvelars.

While secondary to traditional methods of reconstruction, synchronic and diachronic typological observations provide a line of evidence that can contribute to reconstructions where other data is equivocal. However, the lack of extensive cross-linguistic typological survey of sound changes limits comparisons of experimental patterns of variation or errors to patterns of change. (Comrie 2001; Kümmel 2015). In the following section, I present a sample typology of sound changes to provide a comparison to several existing datasets from modern experiments and corpora.

5.2 Test of typological comparisons

I collected a small typology of conditioned and unconditioned developments (989 observations) in Indo-European, Semitic, Sino-Tibetan, Uto-Aztecan, Uralic, Mayan, Austronesian, and Otomanguean,[1] to represent a range of unrelated but relatively well-described language families. Descendant languages were selected from subgroups as widely separated as possible, to minimize correction needed for shared developments.

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[1] Based on Fortson 2010, Kogan 2011, Thurgood and LaPolla 2003, Vogelin et al. 1962, Abondolo 1998, England 1994, Wolff 2010, and Rensch 1976, respectively.

Developments were defined by the starting sound and ending sound, except where interactions motivated well-established intermediate stages; this strategy aimed to avoid biasing the data with assumptions about phonetic naturalness, though it may increase noise by including developments that resulted from multiple sound changes.

The segments included as inputs were ones reconstructed in most of the proto-languages (p t k b d g s z ʃ m n l r j w h); the outputs also include tʃ dʒ ʒ v f. These sounds are of course not identical across languages; differences in phonetic realizations are an important factor to consider in typology, but that inexactness is not the focus of this discussion. Percentages of each outcome were used in correlation tables, to allow for differences in input frequency of each segment. Note that the different datasets have some differences in what consonants were included.

This typology of diachronic developments is positively correlated with confusions collected by Miller and Nicely (1955) in English nonce words, pooled across all listening conditions (white noise of different intensities, some with frequency-based filtering). The correlation is highly significant: $r(174) = 0.93$, $p < 0.001$. This high correlation is largely due to cells for unchanged segments and accurately identified segments. Omitting these cells, the correlation is smaller but still significant: $r(163) = 0.17$, $p = 0.027$. For comparison, some comparisons across conditions of Miller and Nicely's data produce lower correlations.

The correlation between the diachronic typology and misperception patterns in speech-shaped noise collected by Broersma and Scharenborg (2010) in English nonce words is also highly significant: $r(350) = 0.92$, $p < 0.001$. Omitting cells of unchanged segments and correctly identified segments, the correlation is still highly significant: $r(334) = 0.35$, $p < 0.001$.

The diachronic developments are also positively correlated with the data collected by Singh and Black (1966), pooled across all conditions in which the native language of the speaker and listener (Arabic, English, Hindi, and Japanese) was the same. In this study, the adverse condition was the challenge of identifying stimuli which included non-native segments and non-native accents. The correlation with the diachronic data is significant: $r(292) = 0.95$, $p < 0.001$. Omitting cells of unchanged segments and correctly identified segments, the correlation is also highly significant: $r(278) = 0.37$, $p < 0.001$.

Patterns in production errors from van den Broecke and Goldstein's (1980) collection, pooled across the collections from English, German, and Dutch, are also significantly correlated with the diachronic developments: $r(270) = 0.33$, $p < 0.001$. This collection doesn't include a count of correctly produced segments, so this data only provides a comparison for the relative rates of errors.

Perception errors in natural speech from Tang's (2015) compilation across English dialects provide the strongest parallel for diachronic developments. The correlation with diachronic developments is highly significant: $r(382) = 0.94$, $p < 0.001$. This collection includes cells for accurate identifications within the same corpora; omitting cells of unchanged segments and correctly identified segments, the correlation is still highly significant: $r(366) = 0.49$, $p < 0.001$.

6 Conclusions

Having multiple independent lines of evidence in sound change can be beneficial. All experimental methods have limitations, but nonetheless can complement some of the limitations of traditional comparative reconstruction, particularly to demonstrate the plausibility of diachronic developments without known diachronic parallels.

There are limitations to what types of changes experimental data is likely to inform. Patterns in misperception and production errors provide a parallel for phonetically rapid changes; gradual changes will not necessarily exhibit the same similarities. Due to methods of data collection, misperception is generally limited to sounds that already exist within the system, so it provides a parallel only for diachronic changes of mergers or shifts within an existing inventory. Variation in production provides more flexibility in reflecting possibilities for nascent changes and changes not constrained by the existing phonological inventory of a language.

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