Modeling simultaneous convergence and divergence of linguistic features between differently-identifying groups in contact

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Abstract

Evidence suggests that differing group identity can promote divergence between linguistic features despite contact between groups. A growing body of work also suggests that divergence may not occur not across the board in such situations. Rather, some features may diverge, while others converge. We model this outcome as an interaction between low-level imitative tendencies in production and processing and a hypothesized higher-level tendency to choose identifiably in-group utterance targets in production. The general imitative tendency that we model here is the perceptual magnet effect, which over time should promote general convergence between linguistic features over time. In contrast, a tendency to produce identifiably in-group utterances should promote gradual divergence. Within a dynamical-systems model of language, we show that these conflicting mechanisms do not simply cancel out, but rather interact to produce a more complex outcome in which a small number of features diverge against a backdrop of general convergence.

1. Introduction

Convergence of linguistic features among speakers of distinct dialects is a well-documented consequence of contact (Anshen 1969, 1970, Butters 1989, Hock, 1986, Myhill 1988, Rickford 1999, Vaughn-Cooke 1987, Weinrich 1980). Conversely, when contact between groups is low, aspects of their speech can diverge over time. For example, Labov and others have found evidence for divergence between AAVE and white vernacular English in Philadelphia, arguing that this divergence has been caused by increased social segregation of the speech communities (Ash & Myhill 1986, Graff, Labov, Harris 1986, Labov and Harris 1986, Myhill and Harris 1986).

However, degree of contact does not seem to be the only factor influencing divergence, as evidence suggests that dialects in close contact can also show divergence of linguistic features. A large body of work suggests that such divergence under contact is correlated with differential identification of groups in contact (Labov 1972, 1980, Kochetov 2006, Hinton & Pollock 2000, Mendoza-Denton to appear). A classic example of the divergence of phonological features correlating with differential group identification comes from Labov's (1963, 1972) study of the centralization of the diphthongs [ay] and [aw] on Martha's vineyard. The more centralized pronunciation of these diphthongs became a salient marker of 'native Vineyarder'. Thus young men who returned to the island to work tended to centralize [ay] and [aw] more than their fathers, and more than young men who intended to leave the island in the future. While the centralization of [ay] and [aw] was already apparent in older generations of Vinyarders, Labov hypothesized that a social impetus for distinguishing native Vineyarder from non-native drove further change.

Featural divergence and convergence within dialects in contact are not necessarily mutually exclusive, however. A growing body of research suggests that convergence and divergence may occur concurrently among differently identifying groups in contact (Rickford, 1999, Wolfram & Thomas 2002, Hinton & Pollock, Butters 1989). For example, collecting data on AAVE and local white vernaculars in East Palo Alto, Denning (1989) found convergence in the pronunciation of unstressed –i coexisting with the maintenance of a divergent pattern with regard to t/d deletion. He argues that the pronunciation of unstressed –i is not a salient phonological cue symbolizing group membership and thus can converge without threat to identity (Denning 1989).

Despite evidence that the speech of groups in contact can exhibit both convergence and divergence, to our knowledge no model has been proposed to account for this at a mechanistic level. An immediate difficulty lies in explaining how apparently opposing causes could segregate their targets to produce divergence in some features, and convergence in others. In this paper, we propose that within a model of language as a non-linear dynamical system (e.g., Cooper 1999, Kelso 1995, MacWhinney 1998), this pattern is an expected outcome of conflicts between lower level imitative mechanisms and a higher level preference to produce identifiably in-group utterances.

1.1 Language as a dynamical system

The Chomskian program is founded on the hypothesis that the structure of language originates largely in the operation of a highly pre-specified language module in the brain. Within this program, information in linguistic representations is set during acquisition, and in the mature state is minimal, non-redundant and static. Because of its radical restriction on the timing and amount of information storage, this type of model cannot easily accommodate the large and growing body of evidence (i) that speakers process and store fine detail in perceived speech which can influence subsequent perception as well as production (Johnson 1997, Goldinger 2000, reviewed in Pierrehumbert 2003), and (ii) that speakers can slowly shift an acquired pronunciation system towards another over their lifetimes (e.g. Aitchison 2000, Harrington, Palethorpe and Watson 2000, Kerswill 1996). Partially in response to these data, alternative models of language structure and change have arisen in which linguistic categories are richly structured and flexible, rather than sparse and static (e.g., Plaut and Kello 1999, Pierrehumbert 2001, Blevins 2004, Wedel 2004; see MacWhinney 1998, Bybee and McClelland 2005 for reviews). These models open up an exciting avenue for explaining patterns of change, because the mutual influence of perception and production over categories that retain variation creates the conditions for feedback within the system. Complex systems that include feedback loops frequently exhibit self-organization, in which structure arises from the cumulative effect of many similar, repeated interactions over time. When structure arises in this way, conflicting influences on the direction of a particular change can frequently interact in complex ways, rather than simply canceling each other out (for examples see e.g., Plaut and Kello 1999, Cooper 1999, Wedel 2007).

Here, we use a dynamical systems model of language production and processing to investigate the potential interaction of two contributing factors to language change that can come into conflict when differently-identifying groups are in contact within a larger speech community. These factors are (i) lower-level mechanisms in language production and processing that promote featural convergence, and (ii) a hypothesized higher-level tendency to produce recognizably group-identified speech. In computational simulations of many cycles of communication within an abstract model community, we show that this interaction frequently results in divergence of a small number of phonetic features, against a backdrop of general convergence. To our knowledge, this result provides the first attempt at a mechanistic account for concurrent divergence and convergence of language features in contact situations.

2 Simulation as a method for testing hypotheses about language change

Complex dynamical systems are often difficult to analyze experimentally because causes within such systems are often not crisply localized. Instead, causation is widely distributed over many interactions between various elements, all of which leave their cumulative traces in the system in the form of small changes in future interactions. When causation is distributed over space and time in this way, feedback loops often exist that create complex patterns over time (Camazine, Deneubourg, Franks, Sneyd, Theraulaz, and Bonabeau 2001).

As a result of this complexity, it can be impossible or difficult to do actual large scale, controlled experiments on these systems, or to identify natural experiments that approximate these conditions. Instead, computational simulation can provide a proxy system on which we can do well-controlled experiments as a way to further explore the possible workings of the real-world system. These kinds of experiments can help us identify which interactions within the model are functionally central, and even whether some aspects of the model may in fact be unnecessary. Finally, a model that successfully simulates some aspect of real-world behavior points the way to further research within the real-world system that may itself support the model with direct evidence[1]. Within linguistics, examples of the use of simulation to explore models of language structure formation can be found in Hare and Elman (1995) for morphology, Kirby and Hurford (2002) for syntax, Wedel (2007) for phonology, among many others. In this paper, we use simulation to explore how language processing and production mechanisms could drive simultaneous convergence and divergence in features of language spoken by communities in contact. The goal of these simulations is to refine hypotheses concerning the influence of group-identity on variation in speech production which could be further tested in real-world populations.

The simulation architecture we use is based in a general model of language processing and production which assumes that speech categories can retain detailed traces of experience (cf. exemplar models of speech production and perception (Pierrehumbert 2001, 2003, Wedel 2006)). A great deal of evidence shows that language users can retain detailed information about what they hear, and that this information influences subsequent perception and categorization (e.g., Johnson 1997, Eisner and

McQueen 2005). In addition to influencing perception, this perceived phonetic detail influences subsequent production as well (Goldinger 2000). The resulting mutual influence of perception and production creates the opportunity for a feedback loop within a speech community that may function to promote convergence over many cycles of communication (Pierrehumbert 2003, Wedel 2006, 2007).

However, as reviewed above, some speech features may diverge over time between differently-identifying groups in contact, possibly at the very same time that other features are converging. Here, we hypothesize that speakers, consciously or unconsciously, attempt to produce speech that marks them as members of their own group. We show that within a simulation based in plausible mechanisms of production and perception, the conflict between identity-marking and general imitation-driven convergence stably results in the development of a small number of strongly identity-marking features against a backdrop of featural convergence.

3. Methods

The simulations presented here are based on the same exemplar-based architecture employed in Wedel (2006, section 3). In Wedel (2006), this model was used to explore the outcome of conflict between mechanisms of sound production and perception that promote collapse of distinctions on the one hand, and mechanisms of categorization that promote maintenance of distinctions on the other. In these simulations it was shown that this conflict results in a tendency to minimize the total number of sound distinctions in the lexical system over time, without the loss of the ability to express contrast between most lexical items. The same mechanisms are included in the simulations of group-group interaction presented below, with the simple addition of a tendency to choose identifiably in-group production targets (Figure 1).

For ease of reference in the simulations used here the two groups are labeled 'Star-Bellied Sneetches' and 'Plain-Bellied Sneetches' respectively (Seuss, 1961). The lexicon of each Sneetch is constructed as a set of lexical categories, each containing a maximum of fifty of exemplars of previously perceived instances of that category. Because we are focusing on changes in sound-category relationships within an already established community, lexical categories are given rather than emerging from interaction with an environment (see Hutchins and Hazelhurst (2002) for a review), and are shared by the entire community. Exemplars themselves consist of an ordered set of three 'sounds' that can vary continuously on an arbitrary scale from 0 to 100. In each cycle, each Sneetch picks a stored exemplar from each of its categories and utters it, with the addition of a small degree of Gaussian error, to one other randomly chosen Sneetch. That Sneetch compares the perceived utterance to the exemplars in all of its own lexical categories, and stores it as a new exemplar in the most similar category, replacing the oldest previously stored exemplar[2].

Because each perceived and stored exemplar can in turn serve as a model for production in a later round, this architecture creates a production-perception feedback loop that allows community-wide shifts in pronunciation over time. In the context of this feedback loop, experimentally supported mechanisms for both speech production and perception should promote convergence of sound features within a language community. At the most general level, within a perception/production feedback loop any between-category errors result in increased overlap between category contents, and therefore greater similarity. More specifically, in production, motor consolidation biases execution of gestures in the direction of past practice, creating an attractor promoting gradual entrenchment of gestural categories (Zanone and Kelso 1997). In perception, the perceptual magnet effect (Kuhl 1991) creates another attractor with a similar effect (Oudeyer 2002). In the perceptual magnet effect, sounds are perceived as closer to centers of previously experienced sound distributions than they actually are. Over many cycles of production and perception, this effect creates an attractor promoting steady entrenchment of sound categories around a single value. Because entrenchment in production and perception have similar effects at this level of abstraction, for simplicity only the perceptual magnet effect is modeled here. To model this effect, each sound in an incoming percept is biased slightly toward previously stored sounds in relation to their distance and frequency (Guenther and Gjaja 1997; described in more detail in Wedel (2006)). The result should be a steady tendency within the population of speakers in the community to produce ever more similar sounds (Wedel 2006, 2007)[3].

In addition to these elements of the model, the effects of various biases on the choice of a speaker's production model are compared in the simulation architecture employed here. These are introduced in turn as needed in the results section below.

4. Results

The starting lexicons for Star-Bellied and Plain-Bellied Sneetches are shown in Figure 2. Each lexicon contains five lexical categories, each seeded with 10 identical word exemplars with features identifying them as deriving from the respective in-group. As cycles of communication continue, the set of exemplars in each lexicon grows up to a maximum of 50. The words of the Plain-Bellied Sneetches each contain three ‘sounds’ taken from the set {10, 30, 50, 70, 90}, while the words of the Star-Bellied Sneetches contain the same words, except that the sounds are shifted higher by three units. Although the ‘pronunciations’ of words in each category are distinct between the two groups, they are more similar to each other than to words in other categories, allowing successful word recognition in communication between the two groups from the start.

In each cycle, each member of each group picks a random listener from the whole set of speakers in the simulation and utters a word (with a small addition of Gaussian noise) corresponding to each of its lexical categories to that listener. The listener in turn compares the percept to all the exemplars in its lexicon, and stores it as a new exemplar in the most similar word category including a feature identifying the group of the speaker. The perceptual magnet effect is included as part of the model of perception, with the result that the sounds in the percept categorized by the listener tend to be warped slightly toward sounds previously perceived by that listener in relation to frequency and similarity (Guenther and Gjaja 1997). This effect has been theorized to operate at the level of audition (Guenther and Gjaja, Oudeyer 2002), and so our modeled listeners do not respond distinctly to the identity of the speaker at this level. This results in a constant slow tendency for similar sounds to become yet more alike across the entire speech community over many cycles of production and perception (Wedel 2006).

4.1 Change without speaker bias

The factor under study in these simulations is bias on the part of speakers in the choice of models for production. We begin with a control simulation in which there is no bias on the part of speakers in production model choice, and then introduce several different biases in turn. Within the control simulation, as a speaker decides to produce a word corresponding to one of the lexical categories, it chooses a single exemplar at random from that category in memory, with no regard to whether that exemplar originated with a Star-Bellied or Plain-Bellied Sneetch, and produces it with some small degree of Gaussian variation. The listener in turn categorizes and stores the percept as a new exemplar, which may serve as a production model in some future production event from that category.

In this case, where there is no identification difference between the two groups, the distinct ‘accents’ of the two groups quickly merge (Figures 3a, b, c). This derives from two features of the model. First, the perceptual magnet effect continually warps perception toward previous experience, creating an attractor that promotes entrenchment across auditory dimensions (Wedel 2006). In addition, however, in this simulation stored exemplars do not persist indefinitely, but slowly decay and turn over with time (Pierrehumbert 2001). The greater likelihood of loss of less-frequent outliers relative to higher-frequency variants promotes entrenchment as well (Wedel 2006). Within this simulation, this is parallel to loss of uncommon variants of some category in a speech community through forgetting.

4.2 Change when speakers imitate speech of their own group.

We might hypothesize that group identification effects in language change occur because speakers simply prefer to imitate members of their own group, with no regard to others. In this simple variant of our simulation architecture, production models are simply chosen at random from the set of exemplars that contain a feature identifying them as deriving from a member of the speaker's own group. The results of a representative simulation are shown in Figure 4. Here, we can see that although it takes a little longer, the perceptual magnet effect still wins out in the end, eventually eliminating intergroup pronunciation distinctions. Within this simulation, this occurs because the level of noise is not sufficient to entirely swamp out the attractor created by the perceptual magnet effect. In this simulation, we found that in order to diminish the effect of the attractor created by perceptual warping sufficiently to allow Star-Bellied and Plain-Bellied Sneetch pronunciations to diverge, we needed to increase the noise level in production to the point that sound categories overlapped to an implausible degree (not shown).

4.3 Change when speakers choose identifiably in-group production targets

We saw above that imitation of members of the in-group in production is not sufficient to promote featural divergence between two groups in contact. Instead, it may be more likely that speakers choose production models that clearly <u>identify</u> them as members of their own group. To do this, they must choose word production targets that are not only like those of their own group, but that are also recognizably unlike those of the out-group.

Specifically, this approach assumes that speakers are not maximizing difference per se, but rather the probability that they will be successfully identified as a member of their own group. As a consequence, once a certain degree of difference is reached, increasing difference does not increase successful identification as member of a particular group.

By hypothesis, the choice of production target by a speaker is biased toward those exemplars that are distinct from stored exemplars of the out-group. To model this, the segments of each in-group tagged exemplar from a category are compared to the corresponding segments of each out-group tagged exemplar from that category, and an overall distinctiveness value is calculated for that in-group exemplar. Production targets are probabilistically chosen from the in-group exemplars in relation to this calculated distinctiveness value. To model the sensitivity of the system to identification, rather than raw difference, distinctiveness is calculated with a sigmoid function, creating a saturable response of the system to difference. As a consequence, the system does not strongly distinguish between in-group exemplars that are already very distinct from the out-group pronunciations. As a result, once a particular threshold is passed, increasing difference of an in-group exemplar from the out-group pronunciation does not make it increasingly likely to be chosen as a production target.

Results from a representative simulation are shown in figure 5. Here, we see that some of the corresponding sounds in the Star-Bellied and Plain-Bellied Sneetch pronunciations converge, just as in figures 3 and 4 above, but that others stably diverge. Representative exemplars in the two Sneetch groups at cycle 500 are shown in figure 6. Note that the ‘same’ sounds in distinct words all diverge in parallel, even though there is no overt sound category level within the simulation architecture. This parallel divergence across words is due to the attractor set up by the perceptual magnet effect which tends to keep similar sounds similar.

In twenty repetitions of simulations with these starting conditions, two simulations resulted in three divergences out of five corresponding sounds, twelve resulted in two divergences out of four corresponding sounds, six in one divergence, and two in no divergences. Multiple divergences is the most common outcome because not every sound is in every word. As a consequence, multiple diverging sounds are necessary to allow successful group identification in every utterance. However, not every sound need diverge, because in this model the domain over which a Sneetch is attempting to identify itself is the word, not the sound. As long as at least one sound in a word-exemplar is recognizably distinct from the out-group pronunciation, that exemplar has a good chance of being chosen as a model for production. We can see then that the success of this model in accounting for simultaneous convergence and divergence of sound patterns rests on the hypothesis that speakers identify themselves in utterance domains larger than that of the sound.

Note that within the architecture employed here, an initial starting asymmetry between the Star-Bellied and Plain-Bellied Sneetch pronunciations is not required for divergence to occur. Noise in production and perception continually injects variation into the set of exemplars, with the result that sooner or later a small average difference will arise in a particular words' pronunciation between the two groups. The tendency to choose production targets that can be identified as characteristic of the speaker's group will tend to accentuate any small difference within that lexical category, providing for eventual divergence even in the absence of initial differences.

At the same time, the system will capitalize on any larger/more salient difference that exists at the beginning of the simulation, fitting with the hypothesis that the dialectal differences that survive contact and diverge are those that are most salient (e.g., Denning 1989). To model this, we altered the target-choice algorithm to double its relative sensitivity to in-group/out-group pronunciation differences in sounds with values less than 50. When we did this, we found that diverging sounds were significantly more likely to be found within this range, while sounds with an average value of greater than 50 were more likely to converge (not shown).

4.4 Change when communication between groups is prevented

As an additional control, we ran a set of simulations in which the Sneetch groups spoke and listened to only members of their own group. With no inter-group contact, their pronunciations should evolve independently, resulting in net divergence over time under the influence of random noise. Divergence in cases of low or no contact has been previously modeled through simulation by a number of other researchers (reviewed in Livingstone 2002), and this result was confirmed within our simulation architecture (not shown).

5. Discussion

The available experimental evidence suggests that differently identifying groups within a speech community may exhibit simultaneous convergence and divergence of distinct linguistic features over time, rather than just global convergence or divergence (Butters 1989, Denning 1989, Rickford 1999, Hinton and Pollock 2000, Thomas and Wolfram 2002). As noted by Spears (in Fasold et al 1987: 48-55), this implies that divergence within a speech community does not have a broadly acting cause that affects all linguistic features equally. Working within a simple dynamical systems model of language use based on plausible biases on perception and production, we have presented simulations that exhibit just this property. Multiple runs of the model show that simultaneous convergence and divergence of distinct linguistic features is in fact the most common outcome given the architecture of the simulation. Five properties of the model interact to produce this outcome.

1. Rich memory. A wide range of evidence shows that lexical memory contains a wealth of linguistic as well as non-linguistic detail that can be associated with individual utterances. This finding is modeled here by having the speakers' lexical categories populated with a set of exemplars of previously perceived percepts, tagged not only with phonological information, but also with the group identity of the source.
2. Perception-production feedback loops. Feedback loops operate in language over a wide range of interactions and timescales, from inter-generational transmission to interpersonal discourse. In concert with rich lexical memory that can retain variation, these feedback loops can amplify and channel language change. Feedback is incorporated into this model through the storage of percepts as new exemplars, which then can serve as targets in subsequent production.

3. Entrenchment. Here, we modeled entrenchment through the perceptual magnet effect, which has been proposed to operate at a stage prior to percept categorization (Guenther and Gjaja 1997). The perceptual magnet effect creates a non-linear attractor in perception, warping sound percepts toward previously experienced sounds in relation to frequency and similarity. This creates a pressure toward global convergence within a speech community.
4. Speaker bias toward production of group-identifying utterances. We modeled this here by biasing speakers toward a choice of word production targets that were distinct from the average out-group pronunciation. Critically, divergence of word pronunciation in the context of general convergence of sound pronunciation requires that speakers must be satisfied with in-group/out-group distinction in their utterances in domains that are larger than that of the sound. In this simple simulation, that domain was the word. In the real-world, the domains over which speakers are sensitive to difference may vary with context, and should depend on the kind of difference at hand, i.e., phonological, syntactic or semantic.

Denning (1989) proposes that divergence will be tend to be found in more salient features, while less salient features will be more likely to converge. Hock (1986, p. 502) provides an example of limited convergence that is compatible with the view that salience can influence the loci of convergence and divergence among differently identifying groups in contact. In Kupwar, at the border of the Indian states of Maharashtra and Karnataka, the Urdu, Kannada, Marathi, and Telugu languages are spoken by four interacting groups which differ in prestige. There is little borrowing of lexical items between the groups, but surface structures of the languages show convergence relative to the spoken forms of these languages outside Kupwar. This can be explained if the use of an out-group lexical item in speech is more salient in production than use of an out-group identified sentence structure. To explore this general hypothesis within our simulation architecture, we modeled differences in salience by doubling the sensitivity of the target-choice algorithm to in-group/out-group pronunciation differences in the lower half of the sound continuum. Under these conditions, we found that divergence was significantly more likely to emerge among sounds in the lower half of the sound continuum, suggesting that this architecture can be extended as starting model of the differential effects of salience on loci of divergence and convergence in language contact.

There are a many additional potentially relevant sources of influence on patterns of convergence/divergence that were not included in this model for simplicity. For example, a further source of concentration of divergence among particular features not modeled here lies in any kind of attentional feedback, in which greater difference in a particular feature between groups creates greater attention to that feature, further encouraging its use as a group-marker. Likewise, we modeled change along a continuous dimension in this paper in order to illustrate smooth changes in behavior over time. However, this general approach should function as well within systems including more discrete linguistic categories, such as lexical or syntactic structures. The important requirements of any model for this extension are (i) that the model includes some mechanism for frequency of past use to influence probability of future use (e.g., as do exemplar models), and (ii) that speakers have the ability to identify and choose distinct words or structures to express similar propositions. In this case, systemic change to favor forms associated with the in-group can be initiated through changes in relative frequencies of variants, as when a particular form becomes more frequent in one group than in another. This is essentially how change occurs in the simulations presented here, although at a higher level of organization.

Simulations are particularly useful when they provide hypotheses that can be tested through experiments in the actual system of interest. Within the simulation architecture used here, we found that preferential imitation of in-group utterances was not sufficient to drive featural divergence. We hypothesize that this may be generally true whenever lower-level, automatic processes promote overall convergence, as modeled here through the perceptual magnet effect. Instead, we found that divergence required preferential imitation of utterances that were unlike those of the out-group. This could be tested by asking whether real speakers tend to choose more highly divergent forms for utterances in situations of group-group competition, rather than simply forms that are most frequently associated with their own group as measured in more neutral situations.

Endnotes

1. A currently relevant example of this approach to learning about complex systems is the use of computational climate models to investigate the factors involved in global warming.

2. The rate of change in the system is inversely correlated with the number of exemplars, such that a smaller exemplar store allows us to see changes more quickly (Wedel 2006).

3. Left unopposed, this tendency would eventually result in collapse of all distinctions. This tendency is balanced by competition between lexical categories for percepts (Wedel 2004, 2006)

References

Aitchison, Jean. (2000). Psycholinguistic perspectives on language change. In Janda, R. D. and Joseph, B. D. (eds.) *Handbook of historical linguistics.* Oxford: Blackwell.

Anshen, Frank. (1969). Speech Variation Among Negroes in a Small Southern Community. Diss. New York U.

Anshen, Frank. (1970). A Sociolinguistic Analysis of a Sound Change. *Language Sciences* 9: 20-21.

Ash, Sharon and John Myhill. (1986). Linguistic Correlates of Inter-Ethnic Contact. In Eds D. Sankoff *Diversity & Diachrony*. Philedelphia: John Benjamins Publishing Co. Pp. 33-44.

Blevins, Juliette (2004). *Evolutionary Phonology: The emergence of sound patterns.* Cambridge: Cambridge University Press.

Butters, Ronald R. (1989). *The Death of Black English: Convergence and divergence in Black and White vernaculars.* Frankfurt: Verlag Peter Lang GmbH.

Bybee, Joan and James L. McClelland. (2005). Alternatives to the combinatorial paradigm of linguistic theory based on domain general principles of human cognition. In *The Role of Linguistics in Cognitive Science*, ed. Nancy A. Ritter. Special Issue of *The Linguistic Review* 22(2-4). 381-410.

Camazine, Scott, Jean-Louis Deneubourg, Nigel Franks, James Sneyd, Guy Theraulaz, and Eric Bonabeau (2001). *Self-Organization in Biological Systems*. Princeton: Princeton University Press.

Cooper, David L. (1999). *Linguistic attractors: the cognitive dynamics of language acquisition and change*. Amsterdam/Philadelphia: John Benjamins.

Denning, Keith. (1989). Convergence with divergence: A sound change in vernacular Black English. *Language Variation and Change*, Vol. 1 No. 2. Pp. 145-167.

Eckert, Penelope. (1988). Adolescent social structure and the spread of linguistic change. *Language in Society*. 17: 183-207.

Eisner, Frank and James M. McQueen (2006). Perceptual learning in speech: Stability over time. *Journal of the Acoustical Society of America*, 119, 1959-1953.

Fasold, Ralph, William Labov, Faye Boyd Vaughn-Cooke, Guy Bailey, Walt Wolfram, Arthur Spears, and John Rickford. (1987). Are Black and White Vernaculars Diverging? Papers from the NWAVE XIV Panel Discussion. *American Speech*, Vol. 62, No. 1 (Spring), pp. 3-80.

Goldinger, Stephen D. (2000). The role of perceptual episodes in lexical processing. In Cutler, A., McQueen, J. M, and Zondervan, R. *Proceedings of SWAP (Spoken Word Access Processes)*, Nijmegen: Max-Planck-Institute for Psycholinguistics.

Graff, David, William Labov, and Wendell Harris. (1986). Testing Listeners' Reactions to Phonological Markers of Ethnic Identity: A New Method for Sociolinguistic Research. In Eds D. Sankoff *Diversity & Diachrony*. Philedelphia: John Benjamins Publishing Co. Pp. 45-58.

Guenther, Frank H. and Marin N. Gjaja. (1996). The perceptual magnet effect as an emergent property of neural map formation. *Journal of the Acoustical Society of America* 100, 1111-1121.

Guenther, Frank H., Alfonso Nieto-Castanon, Satrajit S. Ghosh, and Jason A. Tourville (2004). Representation of sound categories in auditory cortical maps. *Journal of Speech, Language, and Hearing Research* 47, 46-57.

Hare, Mary. and Jeffrey L. Elman (1995). Learning and morphological change. *Cognition* 56, 61-98.

Harrington, Jonathan, Sallyanne Palethorpe and Catherine I. Watson. (2000). Does the Queen speak the Queen's English? *Nature* 408, 927-928.

Hinton, Linette N. and Karen E. Pollock. (2000). Regional variates in the phonological characteristics of African American Vernacular English. *World Englishes* Vol. 19, No. 1. Pp. 59-71.

Hock, Hans H. (1986). *Principles of Historical Linguistics.* Berlin: Walter de Gruyter & Co. Pp. 380 - 502.

Hutchins, Edwin, and Brian Hazlehurst (2002). Auto-organization and Emergence of Shared Language Structure, In Cangelosi, A. and Parisi, D. (Eds) *Simulating the Evolution of Language*, London: Springer-Verlag, pp 279-305.

Johnson, Keith (1997). Speech perception without speaker normalization. In Keith Johnson and John W. Mullennix (eds.) *Talker Variability in Speech Processing*. San Diego: Academic Press. 145-166.

Kelso, J. A. Scott. (1995). *Dynamic patterns: The self-organization of brain and behavior.* Cambridge, MA: MIT Press.

Kerswill, Paul. (1996). Children, adolescents, and language chaneg. *Language Variation and Change* 8. Pp. 177-202.

Kirby, Simon and James Hurford (2002). The Emergence of Linguistic Structure, An Overview of the Iterated Learning Model. In Angelo Cangelosi and Dominic Parisi (eds.), *Simulating the Evolution of Language*. London: Springer. 121-148.

Kochetov, Alexei. (2006). The role of social factors in the dynamics of sound change: A case study of a Russian dialect. *Language Variation and Change.* 18. Pp. 99-119.

Kuhl, Patricia K. (1991). Human adults and human infants show a 'perceptual magnet effect' for the prototypes of speech categories, monkeys do not. *Perception and Psychophysics*. 50: 93-107.

Labov, William. (1963). The social motivation of a sound change. *Word* 19: 273-309.

Labov, William. (1972). On the mechanism of linguistic change. In (eds.) Gumperz, Hymes

Directions in Sociolinguistics. New York: Holt, Rinehart and Winston, Inc.

Labov, William. (1980). The social origins of sound change. In W. Labov (ed.), *Locating language in time and space.* New York: Academic. 251-265.

Labov, William. and Wendell Harris. (1986). De Facto Segregation of Black & White Vernaculars. In Eds D. Sankoff *Diversity & Diachrony*. Philedelphia: John Benjamins Publishing Co. Pgs. 1-25.

Livingstone, Daniel (2002). The evolution of dialect diversity. In Angelo Cangelosi and Domenico Parisi, (eds.), *Simulating the Evolution of Language*, pp 99-118. London: Springer Verlag.

MacWhinney, Brian (1998). Models of the emergence of language. *Annual Review of Psychology*, 49, 199-227.

Mendoza-Denton, Norma (to appear). *Homegirls: Symbolic Styles in the Making of Latina Girl Gangs*. London: Blackwell.

Myhill, John. (1988). Postvocalic /r/ as an Index of Integration into the BEV Speech Coummnity. *American Speech*, 63 203-213.

Myhill, John and Wendell Harris. (1986). The use of the verbal –s inflection in BEV. In D.

Sankoff, ed., *Diversity and Diachrony.* Philedelphia: John Benjamins Publishing Co. Pp. 291-314.

Oudeyer, Pierre-Ives (2002). Phonemic coding might be a result of sensory-motor coupling dynamics. *Proceedings of the 7th International Conference on the Simulation of Adaptive Behavior*. In Bridget Hallam, Dario Floreano, John Hallam, Gillian Hayes, Jean-Arcady Meyer, (eds.) pp. 406-416. Cambridge: MIT Press.

Pierrehumbert, Janet (2001). Exemplar dynamics: Word frequency, lenition, and contrast. In Joan Bybee and Paul Hopper (eds.) *Frequency effects and the emergence of linguistic structure*. John Benjamins, Amsterdam. 137-157.

Pierrehumbert, Janet (2002). Word-specific phonetics. In Carlos Gussenhoven and Natasha Warner, (eds.) *Laboratory Phonology* 7. Berlin; New York : Mouton de Gruyter.

Pierrehumbert, Janet (2003). Phonetic Diversity, Statistical Learning, and Acquisition of Phonology. *Language and Speech* 46: 115-154.

Plaut, David C. and Christopher T. Kello (1999) The Emergence of Phonology From the Interplay of Speech Comprehension and Production: A Distributed Connectionist Approach. In Brian MacWhinney (ed.), *Emergence of Language*. Hillsdale, NJ: Lawrence Earlbaum Associates.

Rickford, John R. (1999). *African American Vernacular English: Features, Evolution, Educational Implications.* Oxford: Blackwell Publishers.

Seuss, Theodore G. (1961). *The Sneetches, and other stories.* New York: Random House.

Wedel, Andrew. (2004). *Self-organization and categorical behavior in phonology*. Santa Cruz CA: University of California Santa Cruz Ph.D Dissertation.

Wedel, Andrew. (2006). Exemplar models, evolution and language change. *The Linguistic Review* 23: 247-274.

Wedel, Andrew. (2007). Feedback and regularity in the lexicon. *Phonology* 24, 147-85.

Weinreich, Max. (1980). *History of the Yiddish language* (Eng. Trans. by S. Noble) Chicago: U of Chicago Press. Pp. 420-424.

Wolfram, Walt, Thomas, Erik. (2002). *The Development of African American English.* Oxford: Blackwell Publishers Ltd.

Zanone, Pier. G. & J. A. Scott Kelso (1997). Coordination dynamics of learning and transfer: collective and component levels. *Journal of Experimental Psychology: Human Perception and Performance* 23. 1454–1480.

Figure 1. Schematic architecture of the simulation

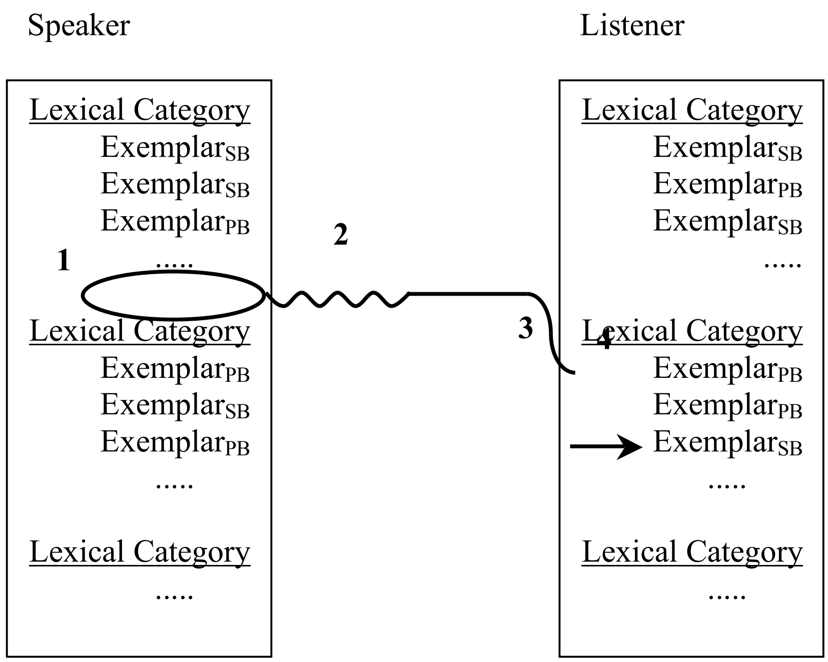


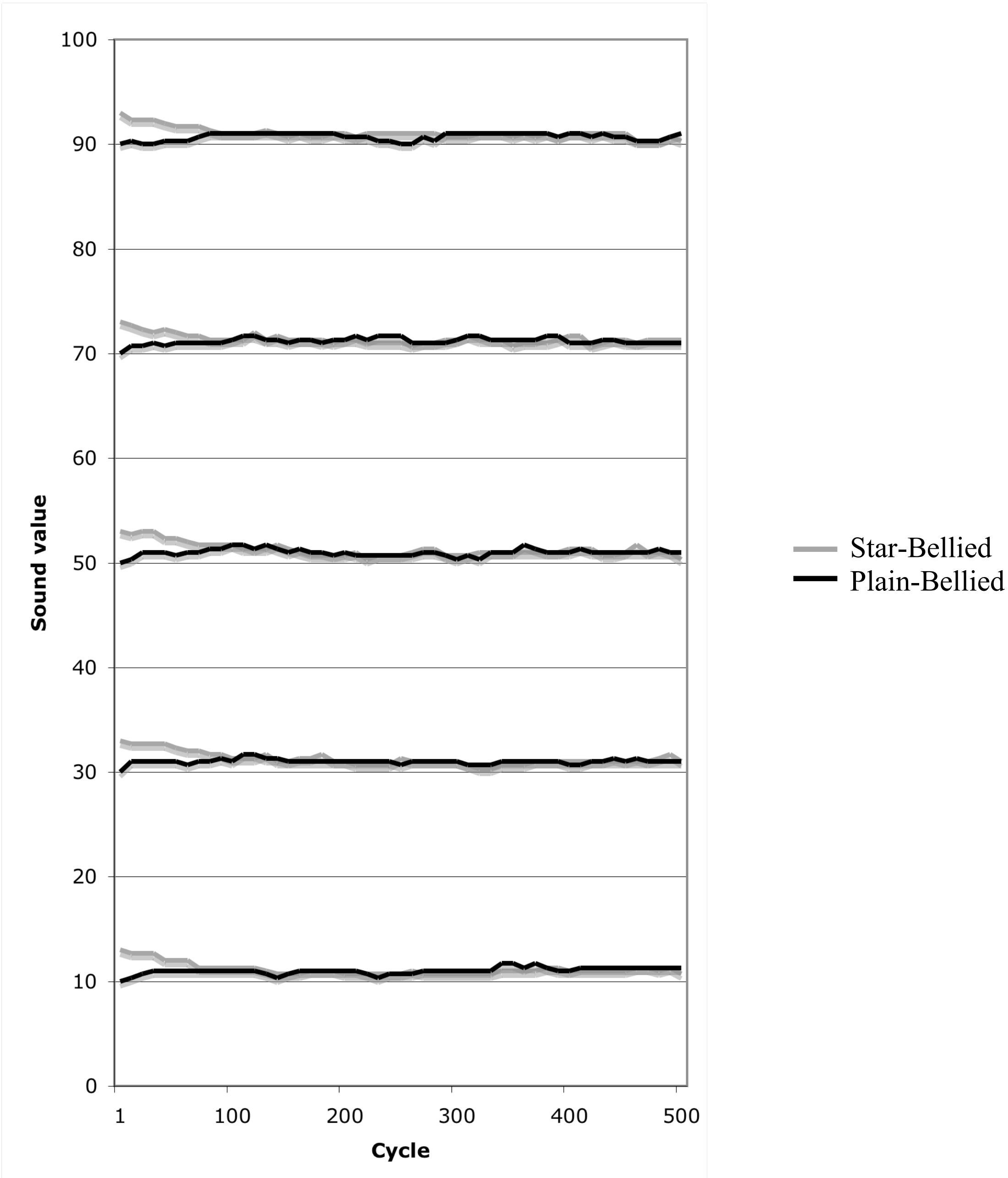
Figure 1 Legend. Each individual starts with a lexicon containing five lexical categories, populated with fifty exemplars. Stored exemplars are potentially different from one another, and are all tagged with a feature corresponding to the group identity of the speaker they originated with, here abbreviated 'SB' for Star-Bellied Sneetch, and 'PB' for Plain-Bellied Sneetch. In each cycle, each Sneetch in turn randomly chooses a listener from the community and produces one utterance each from each of its lexical entries. (1) Choice of production target: Production of an utterance begins with randomly choosing an exemplar out of the store in the lexical entry to use as a production target. (2) Addition of random noise: The exemplar is copied and uttered, with the addition of random Gaussian error that may result in small changes the output value of any sound in the word. (3) Perceptual magnet effect: The listener perceives this utterance through the lens

of its previous experience, in which sound values are slightly warped toward previously stored sound values in relation to frequency and similarity. (4) Categorization: The warped percept is compared to all exemplars in all categories, and the percept is probabilistically stored in the best matching category, replacing the oldest exemplar. For the simulations presented here, the only step that is varied is the choice of production target (1). In section 4.1, choice is random over all exemplars stored in a lexical entry. In section 4.2, exemplars are randomly chosen from the in-group derived exemplars in a lexical entry. In section 4.3, exemplars are chosen from the in-group set, with a bias toward choosing those exemplars that are also distinct from the out-group pronunciation as represented by the set of exemplars stored in that category.

Figure 2. Initial seed lexicons for Star-Bellied and Plain-Bellied Sneetches

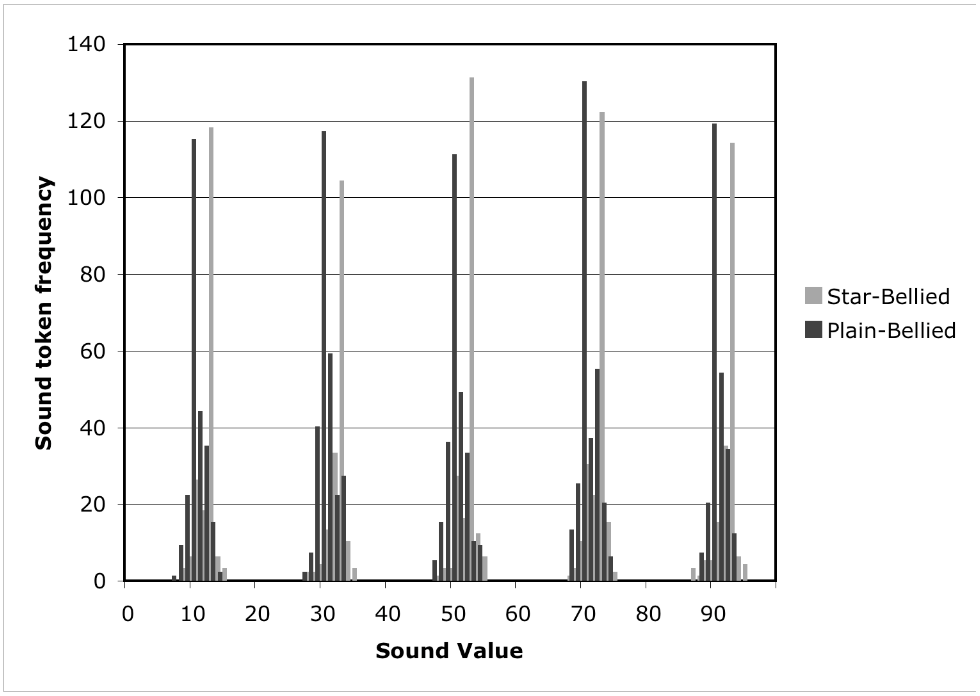
Lexical Category	A	B	C	D	E
Plain-Bellied Sneetches	10 30 50	30 50 70	50 70 90	70 90 10	90 10 30
Star-Bellied Sneetches	13 33 53	33 53 73	53 73 93	73 93 13	93 13 33

Figure 3a. Average sound category value over 500 cycles with no group preference.

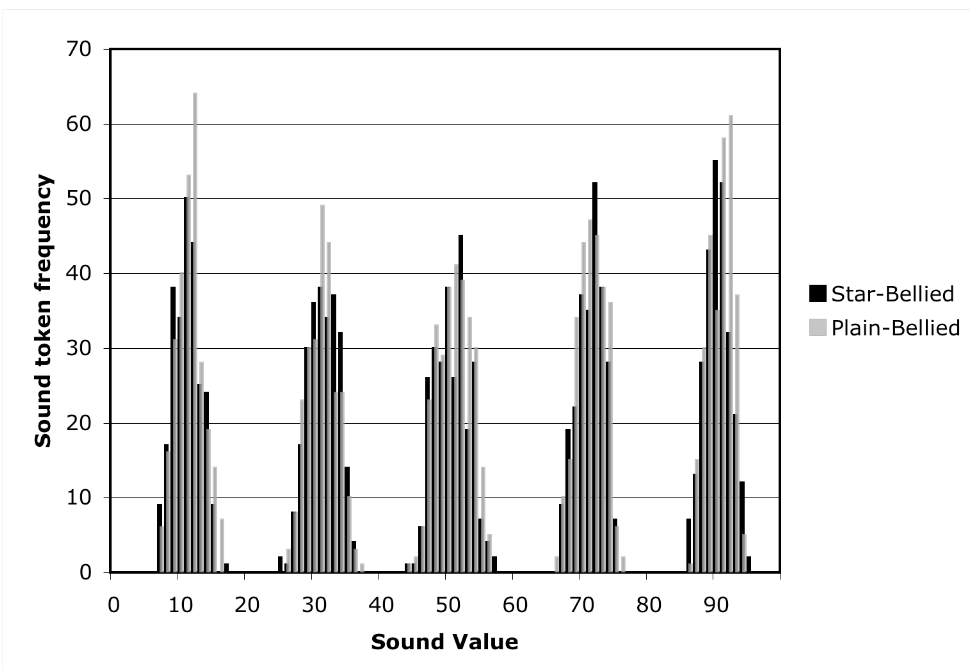


Legend: Gray and black lines represent the averages of sound categories over all lexical items for Star-Bellied and Plain-Bellied Sneetches, respectively. Corresponding categories in the two groups are displaced by three sound units at the start of the simulation (10 versus 13, 30 versus 33, etc.). Within 100 cycles, the averages converge.

Figure 3b. Individual sound values at cycle 50 with no group preference.

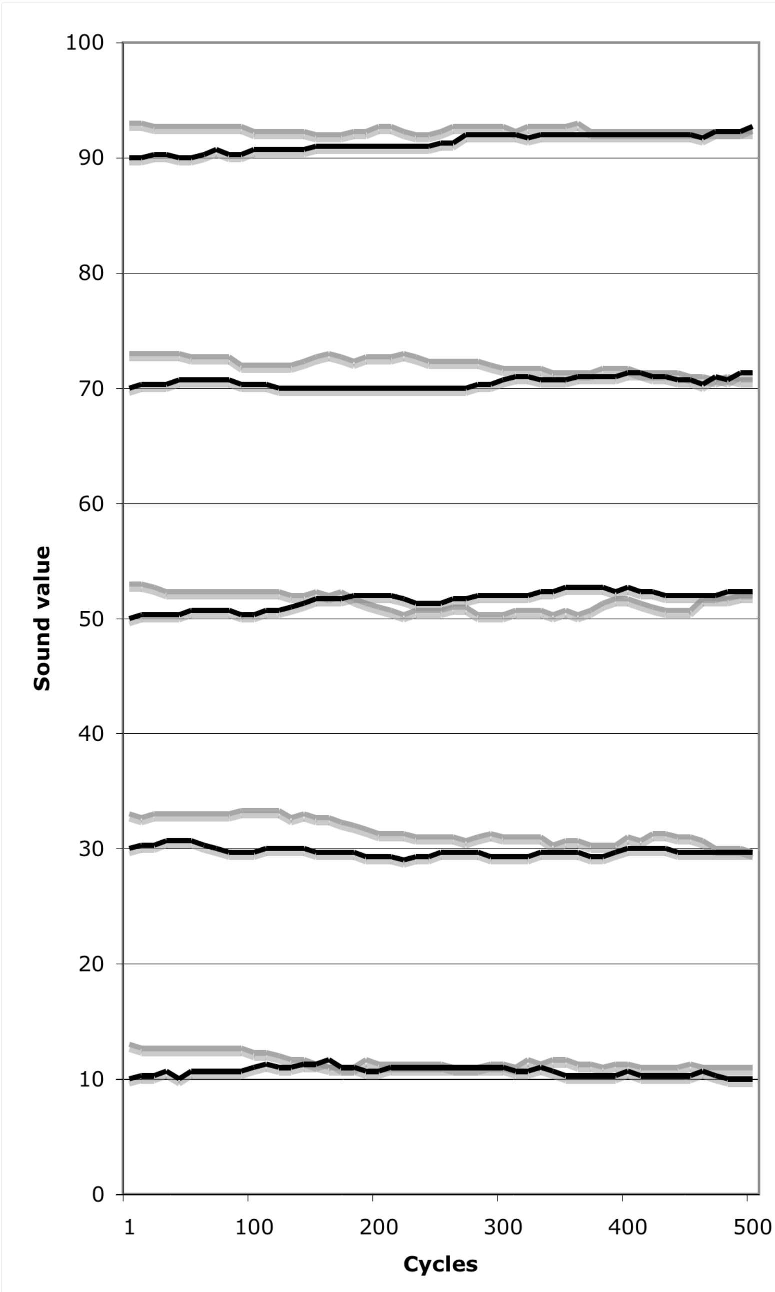


3c. Sound values at cycle 500 with no group preference.



Legend: Gray and black bars represent sound value token frequencies over all lexical items for Star-Bellied and Plain-Bellied Sneetches, respectively. At cycle 50, the initial displacement of sound values can still be seen in the distribution of actual sound values. At cycle 500, the merger of corresponding sounds can be seen in the distributions of sound values, which are largely coextensive.

Figure 4a. Average sound category value over 500 cycles with an in-group imitation preference.



Legend: Gray and black lines represent the averages of sound categories over all lexical items for Star-Bellied and Plain-Bellied Sneetches, respectively. Corresponding categories in the two groups are displaced by three sound units at the start of the simulation. Within several hundred cycles, the averages have largely converged.

Figure 4b. Sound token values at cycle 50 with an in-group imitation preference.

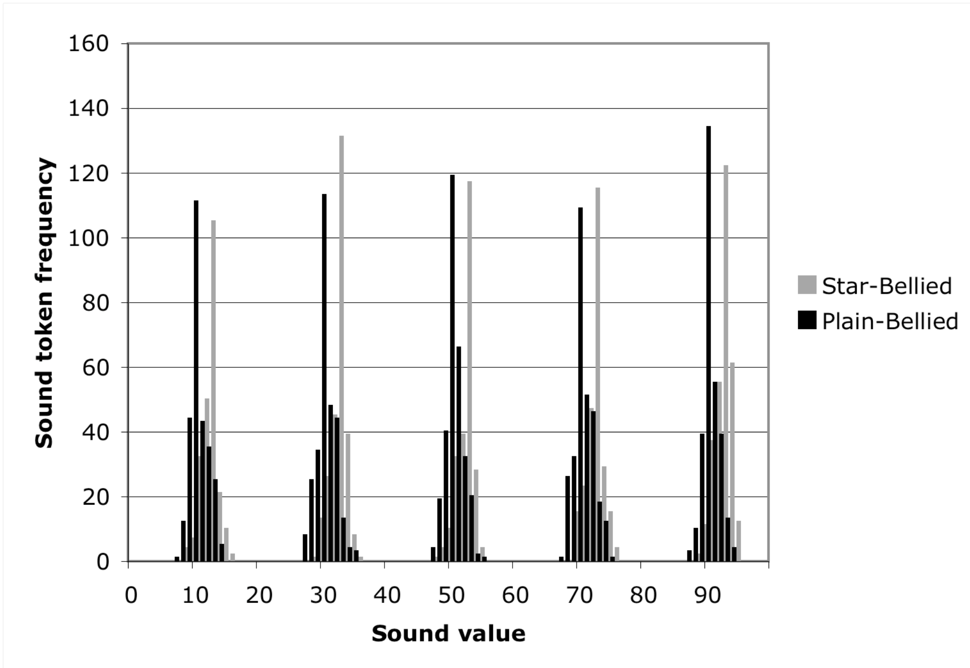
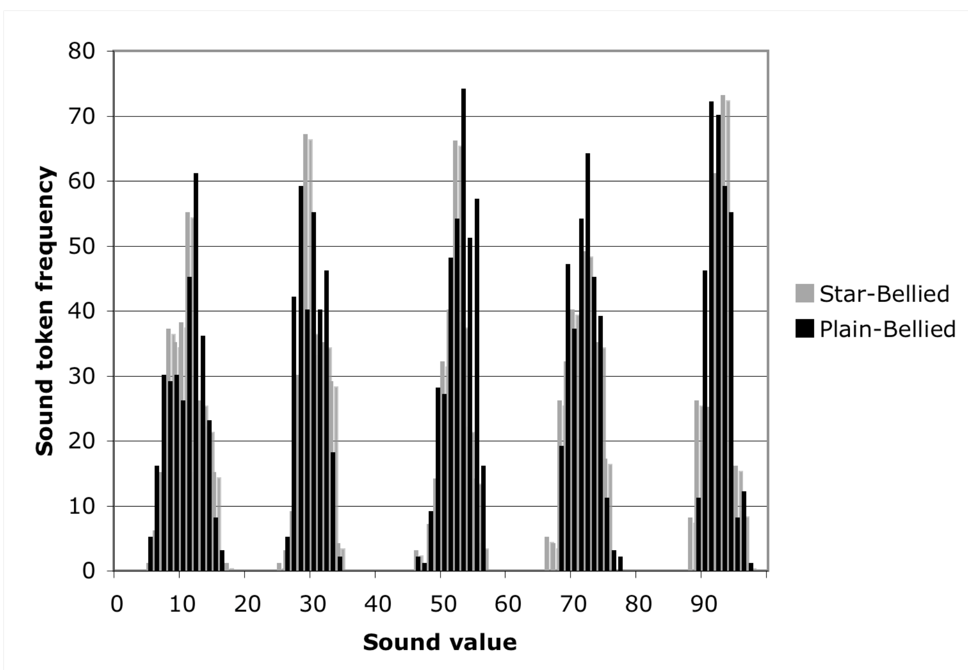
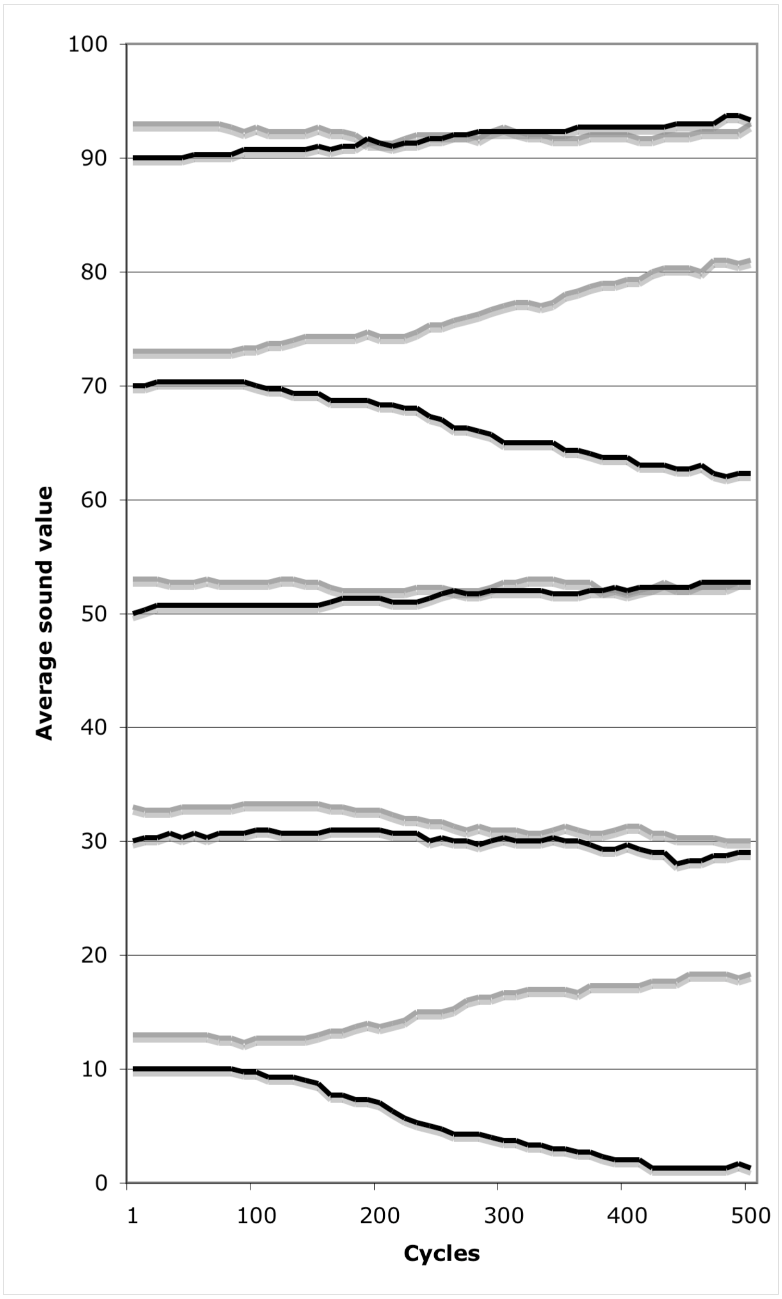


Figure 4c. Sound values at cycle 500 with an in-group imitation preference.



Legend: Gray and black bars represent sound value token frequencies over all lexical items for Star-Bellied and Plain-Bellied Sneetches, respectively. At cycle 50, the initial displacement of sound values can still be seen in the distribution of sound values. At cycle 500, the merger of corresponding sounds can be seen in the distributions of sound values, which are largely coextensive.

Figure 5a. Average sound category value over 500 cycles with a preference for imitating in-group identifying exemplars.



Legend: Gray and black lines represent the averages of sound categories over all lexical items for Star-Bellied and Plain-Bellied Sneetches, respectively. Corresponding categories in the two groups are displaced by three sound units at the start of the simulation (10 versus 13, 30 versus 33, etc.). By 500 cycles, corresponding sounds centered near 30, 50 and 90 have converged, while those originally centered near 10 and 70 have diverged.

Figure 5b. Sound values at cycle 50 with a preference for imitating group-identifying exemplars.

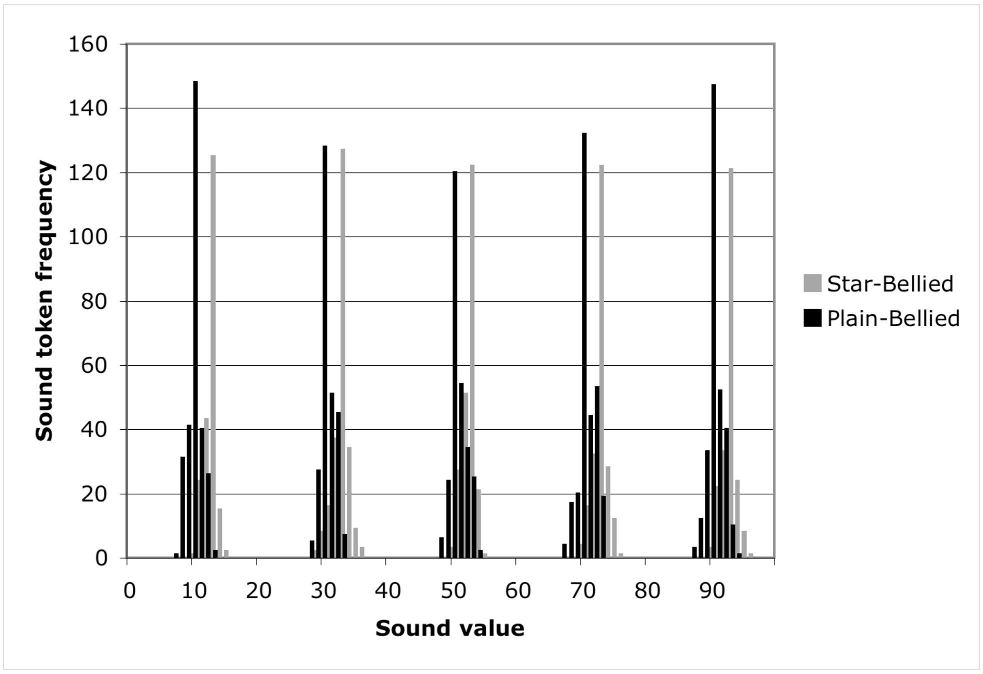
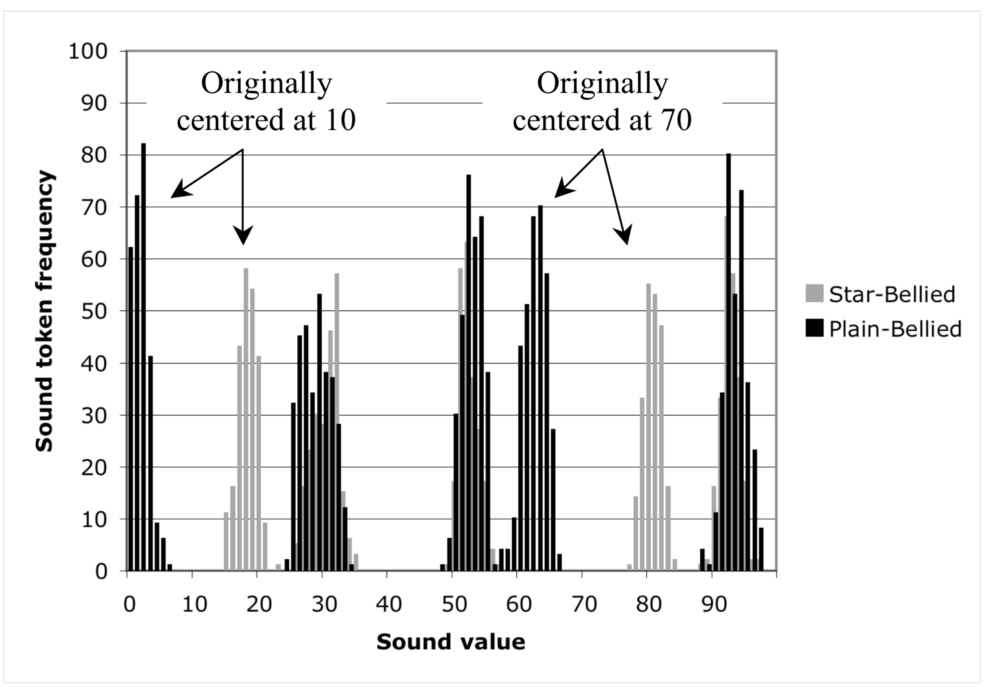


Figure 5c. Sound values at cycle 500 with a preference for imitating group-identifying exemplars.



Legend: Gray and black bars represent sound value token frequencies over all lexical items for Star-Bellied and Plain-Bellied Sneetches, respectively. At cycle 50, the initial displacement of sound values can be seen in the distribution of sound values. By 500 cycles, corresponding sounds centered near 30, 50 and 90 have converged, while those originally centered near 10 and 70 have diverged.

Figure 6. Average exemplar values in the Star-Bellied and Plain-Bellied Sneetch lexicons at cycle 500

Lexical Category	A	B	C	D	E
Plain-Bellied Sneetches	1 29 53	30 53 81	53 81 93	80 92 1	93 2 29
Star-Bellied Sneetches	18 30 53	31 52 62	52 62 93	62 93 19	93 17 30