

# Speech, sign, and the emergence of dual patterning

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Submitted to the faculty of the Department of Linguistics in partial fulfillment  
of the requirements for the degree of Bachelor of Arts

Department of Linguistics  
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April 2019

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## Acknowledgements

All thanks go first and foremost to Natalie Weber, whose patience and kindness are endless and whose encouragement and guidance were indispensable.

Hadas Kotek and Raffaella Zanuttini guided us all through this process with good humor, good advice, and much-needed sense of perspective.

Anelisa, James, Jay, Jisu, Magda, Noah, and Will were a constant inspiration and a faithful support group.

Whether they know it or not, David Watts, Jason Shaw, Jessica Tanner, and Marieke Schouwstra influenced this work profoundly and I'm grateful to have been their student.

And to my parents—your love and support make all of this possible.

## 1. Introduction

The search for universals in language, and the attempt to understand what underlies them, is one of the major domains of all linguistic inquiry. Pursuing it well requires an appreciation of the incredible diversity of human languages, not just of their remarkable commonalities. This thesis is a look at one particular universal—duality of patterning—and an experimental paradigm that has been used to study it. I aim to reconsider this body of work in light of what we know about sign languages, and in particular the phonologies of young or emerging signs. The methods of previous studies are not well aligned with the data from sign languages: this misalignment represents a missed opportunity for comparison and reveals a broader problem of experimental models that ignore the role of modality. I propose a modified version of these methods that would more fully exploit our knowledge of sign language emergence.

Section two will begin with some framing of evolutionary linguistics as a perspective from which to approach the question of universals, and examine in detail the definition and history of the specific phenomenon, dual patterning, around which the rest of the essay revolves. Section three presents the experimental model of iterated learning and the requirements for applying this model to phonology; it ends with a detailed summary of the methods and findings of one particular study in this vein. In section four, I discuss the problems with these methods in light of sign languages—in particular, their use of sequential substructure as the sole proxy for phonology. Section five argues for gesture as an experimental modality and draws out the connection to the gesture-derived grammars of emerging sign languages. Finally, section six considers practical challenges to implementing this method and addresses some lingering questions about the meaning of these findings for the big-picture issues with which the essay begins.

## 2. Background

The first aim of this essay is to examine certain existing experiments that study the emergence of dual patterning by means of an iterated-learning model. Both of these concepts will require some context. Because they are historically connected under the broad umbrella of evolutionary linguistics, I begin with a brief description of the place of evolution in thinking about language. I then review why dual patterning, an abstraction of phonological structure, has enjoyed such a central place in writing about language origins, and position it as a universal and possibly defining feature of language.

## 2.1 Evolutionary linguistics

Language is universal among modern humans—there is no normal individual and no society that has ever been known to lack it. At the same time, though they may have other interesting and sophisticated modes of communication, there is no other animal species that has anything like language, even among our nearest biological relations. The use of language is a distinctive derived trait of the human species, meaning that it arose in our lineage at some time since the split with our closest living relatives. Such a trait is of interest because it is, by definition, part of what characterizes us as a unique species. We might like to know when in our evolutionary history it arose; what the physical, ecological, and social characteristics of the people it arose in were; what pre-existing traits it built upon or repurposed; what its initial precursors were and what selective pressures favored their emergence; how it progressed into its current form and what selective pressures favored its development (Christiansen and Kirby 2003).

Obviously, not all of these questions lie within the scope of linguistics as a field. Evolutionary linguistics consists of the approach to these problems by the methods and with the perspective of linguistics more generally (rather than the methods of archaeology, primatology, bioanthropology, etc.) The questions of language evolution that can be investigated by linguistics are those about the structure of human language itself and its properties and possible histories as a formal system, abstracted away from the individuals and species in the archaeological record (Newmeyer 2003). An understanding of these processes would help us understand the relationship of different aspects of language, their cognitive underpinnings, their pragmatic functions, and their formal structures. It is therefore of interest in understanding the present nature of language every bit as much as the past. It would also offer insight into the possible histories of the aspects of human intelligence and culture that are most unique to our species and have given us our ecological place in the world.

In order to study language in this transitional context, we must rigorously define and distinguish it from the broader cognitive system. One of the key premises and insights of the evolutionary framework is that complex traits like language do not come into being all at once. They are likely to combine and repurpose many existing behaviors and capabilities—so while these contributing traits are essential to language, they may not be unique to language and their own origins probably lie much farther back. For example, the fact that we are social rather than solitary as a species is surely a prerequisite for language—but it is also a trait that we share with all other apes, so studying the evolution of sociality would not tell us anything new about language per se. On the other end, we are similarly not interested in the specific characteristics of existing language families, since by any

estimate the time scale involved is much too deep for these to be relevant. What is of interest, therefore, is language in a narrow sense<sup>1</sup>: those features that are universal among existing languages but not shared with any nonlinguistic human behaviors or nonhuman communication systems. If we could characterize this set of features precisely and understand when and how they arose, we would have solved the most difficult piece of the puzzle.

## 2.2 Duality of patterning as a universal feature of language

For all of the efforts to describe a universal human grammar, there are still relatively few features that can be definitively said to belong to that group. One that has remained a strong candidate is “duality of patterning”—the principle that morphemes, being the smallest meaningful units, can be decomposed into still smaller, discrete, but meaningless linguistic units. The duality here is the existence of two simultaneous layers of linguistic organization. With respect to meaning, each morpheme is an irreducible unit with no internal structure. With respect to contrast, each morpheme consists of some number of independent, discrete elements which distinguish it from other morphemes but do not determine, contribute to, or reflect its meaning. This idea, under the name “double articulation,” was first introduced by André Martinet in his *Eléments de Linguistique Générale*. Referring to the morpheme, he wrote:

“Elle ne saurait être analysée en unités successive plus petites douées de sens : l'ensemble *tête* veut dire « tête » et l'on ne peut attribuer à *tê-* et à *-te* des sens distincts dont la somme serait équivalente à « tête ». Mais la forme vocale est, elle, analysable en une succession d'unités dont chacune contribue à distinguer *tête*, par exemple, d'autres unités comme *bête*, *tante*, ou *terre*. C'est ce qu'on désignera comme la deuxième articulation du langage.”

[It cannot be analyzed as a series of smaller meaningful units. *Tête* means “head” only in its entirety: we cannot attribute to *tê-* and *-te* any distinct meanings whose sum amounts to ‘head.’ But the vocal form is in fact analyzable as a series of units, each of which serve to distinguish *tête* from other [morphological] units like *bête*, *tante*, or *terre*. This is what we will call the ‘second articulation’ of language.]

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<sup>1</sup> This concept and phrasing, from Hauser, Chomsky, and Fitch (2002) is useful, but I do not refer here to their specific conclusions on what that faculty consists of.

We should say from the outset that, despite Martinet’s framing, the definition of dual patterning that has been widely accepted for over sixty years makes no reference to the linearity of units or indeed to any other specific property beyond “meaningless and discrete.” Almost anything that has been proposed as a basic unit of phonology—distinctive features, phonemes, articulatory gestures, tiers—could satisfy this formulation. It is unquestionably true that modern languages exhibit dual patterning. At the same time, as with all universals, we must begin from an agnostic position on when in the development of language it arose and whether it can truly be said to be a necessary, rather than just a pervasive, feature of human grammar.

Dual patterning is just one of the specific universals that could be used as a reference point in language evolution, but it has received a great deal of attention. From a historical perspective, this results largely from the influence of Charles Hockett’s 1960 article, “The Origin of Speech.” Hockett was among the first to propose that the comparative method of evolutionary biology might be able to shed light on questions of language too remote for the comparative method of historical linguistics. Although language itself does not correspond to any known behavior of any other species, our anatomy and social-cooperative life strategies have homologies—cognates—all across the primate family. The article argues that since the most basic capacities and behaviors that enable human language, like vocalizing and information-sharing, are part of our evolutionary inheritance, we can and should study them in relation to their animal homologies and analogies.

Though there is plenty to criticize throughout, Hockett’s framework has remained a touchstone for comparative approaches to language evolution, and the special importance it assigns to dual patterning has elevated it as a subject of inquiry. One thing that stands out as problematic to the modern reader is the extent to which Hockett conflates physical aspects of speech with cognitive aspects of language. Since today we understand the mental language faculty to underlie signed languages as well as spoken ones, it is right to be skeptical of such a framing. If a theory only accounts for languages whose modality is oral/aural and not those that are manual/visual, then it does not really account the narrow faculty of language. Hockett’s perspective though, it not simply outdated or prejudiced. The remainder of this section offers deeper examination of his premises, allowing us to establish what the basis of this outlook really is and what parts of the model are still useful for a sign-inclusive linguistics.

The article lists thirteen so-called “design features” that it claims are universal in human language. In keeping with the comparative lens, they begin with broad properties common to many

animal behaviors, such as the vocal-auditory pathway; move to narrower properties of communication systems like arbitrariness, which is shared with some animal calls; and eventually arrive at distinctively human qualities like displaced reference. The aim is not just to define the decisive, unique cognitive keystones of human language, but to count out the nonunique abilities and qualities that we recruit in support of language, and to situate them in a phylogenetic tree.

Duality of patterning is given the last, most uniquely linguistic spot. The claim is that no other sign systems—not only all animal behaviors but also human paralinguistic communication and structurally complex productions like music—have discrete nonmeaningful units that combine to form their minimal meaningful units. Hockett explicitly relates dual patterning to the large size of human lexicons, observing that as the number of distinct arbitrary signs increases, the more difficult it is to distinguish them on the basis of gross phonetic difference. Indeed, he goes so far as to conjecture that this was the actual historical cause of the development of phonology.

His subject is language behavior, not only the mental language capacity. And since Hockett—this being 1960—thought of language behavior in terms of speech, it was only natural to see the precursors of speech and the precursors of grammar as equally vital in charting the evolution of language. It is necessary to emphasize that evolution is above all a historical lens, concerned with discovering how traits happened to develop into their present states. Describing this trajectory is not the same as describing the “essence” of the trait as it exists today or even the current basis for its selection—on the contrary, a core assumption of the evolutionary framework is that traits are often repurposed. An account that sees the evolution of speech as a part of the evolution of language is therefore only making the claim that the core mental and grammatical developments happened in the medium of speech, that speech is the historical home of our language capacity. It does not imply the claims that language is equivalent to speech, that language can only be fully expressed in speech, or that speech is primary and sign secondary in a synchronic sense. And since the modern understanding is that sign languages do in fact have phonological as well as morphological structure, there is no contradiction that arises from including them.

If so, then duality of patterning is one of those features that are universal in language but wholly specific to it. This would make it a challenging and appropriate test case for any theory of language evolution. If a theory cannot explain how such features emerge, then it has not really explained much about the specific nature of language at all. By the same token, any plausible and grounded proposal for a mechanism by which they emerge certainly deserves attention as a possible account of language origins.



## 2.3 Emergent structure

One perspective that has some success in modeling the emergence of linguistic features is that of language as a system with emergent complexity. This view involves seeing some aspects of the complexity of language not as a completely unique problem that will have a completely unique solution, but as a particularly difficult example of a more general problem.

In general, emergence refers to the process by which systems or entities display properties that are not specified in any of their constituent parts. For example, the behavior of an ant colony, which executes complex strategies of reproduction, food-gathering, and waste disposal that are not completed by any individual ant and not triggered by any individual stimulus, can be viewed as an emergent system. In the broadest sense, the hypothesis is that we can see phenomena at a macro scale that seems like the output of an intentional, unitary agent—but in fact is the result of many agents at a micro scale pursuing individual goals that do not consciously anticipate their collective effect.

This is not yet a solution but merely a category of analyses. How might we model the actual interactions of language users and how could this help us explain the nature of the overall language system? The specific proposal is this: language is a self-replicating, adaptive system that undergoes processes of cultural evolution. Language can be understood not only as a result of human biological evolution and the cognitive makeup that has given us, but also as an evolving entity in its own right that is transmitted through parallel cultural generations of models and acquirers (Kirby 1999, Christiansen and Kirby 2003). In biological evolution, organisms can acquire complex heritable traits through the interface of small variations in reproduction with selective pressures that favor certain of these variants over others. The traits were not specified in any underlying way but emerged from the action of differential reproduction on the variation that naturally exists in a population. Cultural evolution proposes that entities which reproduce themselves in non-genetic ways are also subject to pressures that favor the proliferation of some variants over others, and can therefore acquire complex characteristics through a process that is in several key respects computationally analogous to biological evolution.

Whatever innate components are in play, language in a specific sense is clearly learned from the environment—from existing speakers. These speakers, in turn, acquired their knowledge in the same way from previous speakers. In this process there is no ultimate authority on the form of a language and no external fact of its grammar: it must be constantly reconstructed in the mind of new speakers and the output of that construction will itself constitute the input for the next generation.

This is the fundamental structure of cultural transmission. It is not unique to language, but what is as ever interesting about language is the fact that learners evidently acquire a productive model and not merely an imitation of what they observe.

That line of thinking is not in itself new. What is somewhat newer is the idea that some of the complexity of language might actually be a result of the transmission process and not merely an obstacle to it. To the familiar analyses of acquisition as an interplay between innate capacity and direct experience, we can add the idea of acquisition as a bottleneck for the survival of grammar. The language, like an organism, must “reproduce” itself in the minds of a new generation of speakers in order to survive. In doing so, it is subject to the “selective” pressures of learning and usage. If a language is too complicated to learn or if it is too impoverished to usefully communicate, it will tend not to be transmitted with complete faithfulness. Linguistic structure can therefore arise from the very process of learners constructing their grammars, since—as compared to the mental grammars of their parents—they are likely to exclude any rules that were so difficult to learn that they went unnoticed and include new regularities that compress the information structure of the language or allow it to express formerly unspecified concepts (Smith 2011, Kirby, Griffiths, and Smith 2014).

Two caveats. First, there is clearly much about this process that is very unlike biological evolution. Everyone has exactly two genetic parents but potentially hundreds of cultural and linguistic “parents” (models for learning); cultural-linguistic change can be massively discontinuous in a way that genetic change cannot; linguistic variants do not only “compete” on their learnability and expressive power but also on many more complex social axes. We should understand that the comparison is most useful in a very broad and stripped-down context and is probably not a good way to make predictions about the kinds of historical change that come up naturally today. Second, this concept is not in any kind of fundamental conflict with the idea of certain innate, universal grammatical knowledge or parameters. They enter neatly into this framework as particularly strong or even inviolable constraints on learning (i.e. expectations so strong that, no matter the data, it will always be too difficult for us to infer a contrary rule). Indeed, there is now some logical rigor to the framing of unlearnable rules—rules that are neither found in the worlds’ natural languages nor correctly inferred in artificial ones—as being those forbidden by universal grammar. The point is simply that not every learning constraint needs to be posited as a dedicated piece of mental grammar and that even these more general constraints can induce universal linguistic patterns.

### 3. Iterated learning experiments

One exciting thing about this theoretical lens is that it leads very naturally to an experimental model. The process of acquisition and the generational structure of transmission can be simulated, on a very reduced scale, with the acquisition and transmission of toy “artificial languages,” both on computers and with human participants. By the design of the transmission task and the initial language, it becomes possible to induce the emergence of linguistic (or language-like) structures and complexity over the course of multiple generations. In this section, I give an overview of this iterated-learning model and summarize the key experiments that have applied it to duality of patterning.

#### 3.1 Small-scale models of language evolution

If it is true that the structure of transmission itself—the iterated cycle of acquisition and usage—alters the grammar of language in computationally expected ways, then we might wonder if this same process produces similar results in artificial languages. A laboratory context<sup>2</sup> can model many, many more generations of transmission than we could possibly observe naturalistically, in a linguistically pared-down environment that allows us to narrow in on some particular phenomenon of interest

Instead of teaching the language to every individual from some fixed training set, participants are organized into a “generational” diffusion chain that mimics the transmission structure of real languages. The first set of participants is taught an initial language of the experimenter’s design. But they are required to reproduce rather than simply recognize what they learn, and their outputs are then used as the training data for the next generation of participants. In this way we replicate the key structural aspects of cultural learning: the knowledge is reconstructed solely on the basis of usage, without any reference to an enduring external documentation, and the inferences made by one generation in this acquisition process shape the stimulus available to the next generation.

When the experimental conditions, like the real world, reflect the competing pressures to learn quickly, produce utterances similar to what we were exposed to, produce utterances similar to what other people produce, and accurately map utterances to their real-world referents, artificial languages do develop languagelike structures. That is, relative to the initial language with which the first

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<sup>2</sup> Iterated learning with human participants is what’s relevant to the current discussion, but the model can also be applied to computer simulations (de Boer 2005, de Boer and Zuidema 2010, Kirby, Griffiths, and Smith 2014, Tonkes and Wiles 2002).

generation was seeded, the final language that the last generation produces can develop specific structures solely through the collective alterations of the participants. A few examples of past studies in this vein include Kirby, Cornish and Smith (2008) on the emergence of a simple morphosyntax; Carr et al. (2017) on the division of a semantic space; and Silvey, Kirby, and Smith (2013) on efficient underspecification.

### **3.2 Artificial modalities bypass L1 phonological knowledge**

A necessary feature of any artificial language experiment is that it effectively bypasses the native language competence of its participants in order to access more basic linguistic biases. Otherwise, it is not revealing anything more complicated than interference from the participants' L1 as they attempt to learn a new language. The fact that this is even possible—that monolinguals faced with simple communication tasks readily abandon the patterns of their native language—is already remarkable<sup>3</sup>. But phonology presents some particular challenges in an artificial language. Our native phonologies constrain us at a very basic perceptual level. It is difficult even to properly hear, let alone produce, forms that violate them, and learners tend to apply these biases to new languages as well. In order to escape the direct influence of this knowledge, the artificial language must be perceived and produced with an entirely different system. For this reason, experiments that target phonology tend to use not only an artificial language, or set of symbols, but also an artificial modality, or type of symbol. Any phonological patterning that appears in such a modality can more confidently be interpreted as resulting from underlying cognitive and computational pressures, rather than direct interference. At the same time, working in novel modalities requires a very abstract notion of phonological structure—another advantage of working with dual patterning, which is defined only in terms of the hierarchy and meaningfulness of units and not in terms of their nature or content.

### **3.3 Recent examples**

Del Giudice (2012) and Verhoef et al. (2016) are two very similar experimental attempts to observe duality of patterning emerging in an artificial language. Both use quasi-random initial lexicons that are learned and recalled by human participants in a diffusion chain structure. The lexicon produced by the last member of a chain is examined for combinatorial structure; various constraints ensure this

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<sup>3</sup> To examine and justify this finding in full detail is beyond the scope of this essay, but see for example Goldin-Meadow et al. 2008, Motamedi et al. 2017, Schouwstra 2017.

structure is more phonological than morphological. Though Del Giudice in particular could be more statistically robust, both do find evidence that dual patterning is emerging in their artificial languages. Given the comparatively small size of the lexicons, these results indicate that phonology-like structure has strong enough computational or cognitive advantages that it can emerge even in extremely simplified contexts.

Verhoef et al. use a powerful, if unusual, methodology that deserves a detailed treatment—both to make sense of their results and to demonstrate the type of creative design that is necessary for such work.<sup>4</sup> The symbols of their language are not words or pictures, but short melodies produced on a slide whistle. This has the advantage of being an auditory medium like speech, but still producing only a one-dimensional stream of information (i.e. the height of the slide). An initial set of whistles is generated quasi-randomly in a separate stage.

Each whistle out a lexicon of twelve is randomly assigned a meaning from a set of “novel objects,” which resemble mechanical parts. The experiment has three phases: in learning, participants see each object with its whistle and practice imitating the whistle. In recall, participants select the objects in any order they want and record their whistles from memory. In reinforcement, participants are presented with a whistle and must choose its associated object. This cycle is repeated three times and the output from the final recall round becomes the learning set for the next participant in the chain.

There are two experimental conditions, with the key difference being the mapping of symbols to meanings. In the first, the same meanings are associated with the same symbols throughout the entire diffusion chain. In the second, the lexicon is scrambled between each participant, so that although the whistles are faithfully passed on, each is reassociated with a new meaning.

The final lexicon of each chain is examined for segmental structure—substrings that are common to many symbols and can be combined to (approximately) describe the whole symbol. Because they generate one-dimensional signals over time, the similarity of two substrings can be straightforwardly quantified using measures of the distance between two two-dimensional graphs. Verhoef et al. generate three segmentations (based on pauses, pitch peaks, and velocity peaks) and

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<sup>4</sup> Del Giudice is similar enough conceptually that it will do to summarize only one. He does use a different modality: small line drawings made with an electronic stylus. A key feature of these symbols is that the stylus descends automatically at a fixed rate from the top to the bottom of the screen, so that drawing is completed in a fixed period of time and the participant only controls its horizontal component. This is done to limit overt iconism but also has the effect of reducing the complexity of the signal from two dimensions to one.

choose the one with the lowest entropy. They find a significant decrease in entropy over the entire lexicon, indicating increasing combinatorial structure; because the substrings do not correspond to any discernable similarities between referents, the substructure is considered phonological rather than morphological.<sup>5</sup> There is a significant decrease in recall error over the generations in both conditions—that is, participants later in the chain reproduce their training data more faithfully than those earlier in the chain. This indicates that the lexicon is also increasing in learnability, and hints at the possibility that the statistically observed substructure actually reflects some degree of segmentation in participants’ mental representation of the melodies.

#### 4. Problems with previous studies

Methods and theories that were developed with speech in mind can often benefit from the comparison to sign languages. This is true in general—since signs just are a subset of all existing languages—but especially so in the area of language origins. The newly emerging languages of the present day are all signs, and data from these languages (grounded in an understanding of sign linguistics more generally) are a vital naturalistic point of comparison to any experimental or theoretical treatment of emergent grammars. The intermediate grammatical stages through which these languages progress are a **check on the plausibility** of other results and provide support for the validity of studying language emergence through the behavior of modern people. The goal of the rest of this paper will be to examine work like Verhoef’s and Del Giudice’s in light of sign language phonology and in particular the development of phonological structure in new sign languages.

With this in mind, we should examine the assumptions about the role of modality present in previous work. Eventually, we want to interrogate whether their findings about emergent dual patterning correspond to observations of emerging sign phonologies. But first, we have to consider whether the simplifying methodological assumptions that these studies make about the analogy of artificial modalities to speech are really warranted.

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<sup>5</sup> These results are especially interesting because of the very small number of symbols used. Initial descriptions of duality of patterning had assumed that it arises primarily as a result of a growing lexicon—that as more and more symbols are in use, it becomes impossible to rely on gross phonetic distinctions and categorical structure must be imposed to reduce the burden on memory and perception. That some beginnings of segmental patterning can be detected even in such a small “language” suggests that there are other forces to consider.

## 4.1 Modality is not grammar-neutral

The core assumption of studies in artificial modalities is obviously that the change of modality does not affect the linguistic phenomenon they hope to observe. They necessarily work from the premise that the underlying cognitive and computational processes are not specific to speech or to line drawings, and that the differences between these two are not an obstacle to using one as a model for the other. Indeed, the choice of medium is sometimes so far afield that the implicit claim seems to be not merely that these particular modalities are sufficiently analogous to speech for their purposes, but rather that no two modalities are so different as to pose a problem.

This does not, however, completely align with what we know about the interaction of modality and grammar in natural languages. Of course, language is not actually instantiated in the vast majority of all modalities used in artificial experiments. There are only two that routinely support a full linguistic system: the oral/aural pathway of speech and the manual/visual one of sign. But even just by comparing speech and sign we can see that—especially in the first few generations of a language—there are some typological facts that we have to attribute for now to the effects of modality. Because sign languages are not an actual family or areal group, if we generalize at all about “spoken languages” and “signed languages” then we are acknowledging a role for modality in shaping linguistic structure.

Some of these generalizations may on the surface have little to do with modality—for example, the fact that no known sign language has VSO word order, which is the third most common for spoken languages (de Vos and Pfau 2015). Others are more transparently related to the visual medium, like the systems of noun classifiers found across sign languages. Plenty of spoken languages make use of classifiers, but signs have access to a degree of iconism that can more easily feed this process of grammaticalization. Similarly, classes of verbal agreement—for example, types that inflect for both subject and object—are found in sign languages far out of proportion to their overall prevalence. They can also be analyzed as arising from grammaticalization of spatial iconism (Aronoff, Meir, and Sandler 2005). **Tendencies** like these demonstrate that even in areas like syntax and morphology, which might superficially appear less susceptible than phonology to the influence of different articulators, a change in modality does correspond and even contribute to meaningful typological differences.

This division doesn’t need to be categorical, fundamental, or insurmountable in order to be real and to pose a problem for our methodology. It’s more than enough if we can say: a structure is easier to express in this modality, or a structure is less ambiguous in this modality, or a structure is more stable in this modality. The question is simply whether different physical means of expressing

language amount to different environments through which to channel the mental grammatical capacity—which is almost certainly true—and whether this different initial terrain results in a probabilistically different set of grammars—which also seems partially true.

If so, then we have to acknowledge when designing an experiment that the artificial modality is not a theoretically neutral choice that can be made simply to maximize convenience. It is a choice that is intimately connected to the nature of the linguistic phenomenon under investigation and affects the potential natural language analogues to which the findings can be compared. We will need to make convincing cases for why any given artificial modality is an appropriate choice for studying any given phenomenon and why we do not expect it to produce significantly different grammars than speech (or than sign, as the case may be).

## 4.2 Segments are not modality-neutral

Overall, of course, the fundamental differences between speech and sign are very few. Sign languages do not violate linguistic universals and the great majority of their structure is best understood as arising directly from the same knowledge and mental organization that gives rise to speech. Speech and sign are two instances of one phenomenon; establishing this fact has been one of the major tasks of sign linguistics for over half a century (e.g. Stokoe 1960, Emmorey 2002, Sandler and Lillo-Martin 2006). But unfortunately for this case, the question of phonological units—which ones exist and how they combine to form morphemes—is one of the starkest areas of difference between speech and sign as categories.

In broad terms, the elements of sign phonology are well established. Signs are composed of features like handshape, palm orientation, movement path, and location (Brentari et al. 2018). These features are meaningless in themselves but support contrasts in meaning. A minimal pair can, for example, differ only in handshape or only in location. We can say confidently that these elements fit the definition of phonological units in the dual-pattern model: they are meaningless and discrete, they are constituents of every morpheme, and they are sufficient to distinguish one morpheme from another.

As noted in the original discussion of dual patterning, spoken languages can satisfy this definition at least twice over—both phonemes and distinctive features **fit the bill**.<sup>6</sup> The key difference

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<sup>6</sup> This is true regardless of one's position on the underlying psychological organization or status of any of these objects. This issue is pointedly not a psychological one, but rather a question about the outputs of system themselves as they can



between them is that phonemes are fundamentally sequential, unfolding over time, while features can be articulated simultaneously. Between the two, the elements of sign phonology outlined above are clearly analogous to the feature. Signers do not form first the handshape, followed by an orientation, followed by a location, but rather combine them all into one complex articulation. And although the question of what role sequentiality does play in sign language phonology is somewhat vexed<sup>7</sup>, we can say at a minimum that clusters of features are not articulated in long strings as they are in spoken languages; that a sequential segmentation of sign language would be less efficient from a computational perspective than either a sequential analysis of speech or a featural analysis of sign; and that minimal pairs rarely arise from sequenced elements (Channon 2012, Sandler 2012, van der Hulst 1993, Liddell 1984). Discrete sequential units are not the basic organizing principle of sign language phonologies.

### 4.3 Previous studies target segments

It isn't really surprising that speech and sign, which make use of such different communication channels, would have different ways of breaking down and organizing their respective signals. And it doesn't preclude direct comparison, since speech has its own simultaneous features too. As long as we are studying something that two modalities—natural or artificial—have specifically in common, it won't matter if they differ in other ways. But this, ultimately, is the flaw in existing studies of emergent dual patterning. By their very design they look only for the emergence of sequential phonological structure, blocking the sign comparison before the experiments have even begun.

Despite their different modalities, Verhoef and Del Giudice have an identical computational structure. Both use a signal that has been simplified down to a single dimension, a single number,

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be observed and described. This is necessary if we are to keep duality of patterning as a concept that can be rigorously applied to nonlinguistic (and even nonanimal) systems. The statement is simply that the utterances of a spoken language can be characterized as a set of phonemes, or a set of features, with relatively little loss of information. I am also limiting the discussion here to phonemes and features (excluding other possible units like the articulatory gesture) since, as will shortly be clear, they are the essence of the conflict between sign languages and the relevant experimental work.

<sup>7</sup> In brief, there is clearly a temporal element insofar as the gesture has a beginning and end (and may have intermediate targets to hit as well). Some accounts describe this as analogous to a syllable with a “nucleus” of movement anchored by two locations, while other find it more like the complex gesture involved in articulating even a single speech phoneme. For my purposes, the difference from the role of sequentiality in speech is great enough either way that this question can be set aside—especially in view of its even more marginal place in newly emergent signs.

varying over time. For Verhoef this is the frequency of the slide whistle; for Del Giudice, the position of the stylus on the horizontal axis.<sup>8</sup> It would be impossible for such a signal to develop any simultaneous organization, because it has no simultaneous complexity; the only type of substructure it could accommodate would be one that unfolds over time. This method therefore commits in advance to the segment as its proxy for emergent phonological structure. In so choosing, these experiments stake out a position that is unavoidably connected with speech and prevents meaningful comparison with emerging sign languages.

## **5. Gesture as a solution**

It should be clear that if iterated learning experiments are to be useful—in general but especially in phonology—the choice of modality cannot be a convenience or an afterthought. I propose that gesture is an ideal modality for studying the particular problem of duality of patterning. It is both novel and natural: unknown to most individuals but a proven site for language in general. Furthermore, the study of emerging sign languages provides an alternative account of the first generations of a new gestural phonology; the results of an experiment in gesture would be much better positioned to make use of this evidence.

This section begins with the case for gesture as a valid medium for experimentation and as the basic precursor to new sign languages. I will then lay out some ways in which new sign languages are not an ideal case of emergence, and others in which they do present a strong example. The final subsection will examine specific findings on the development of phonology in these languages and

### **5.1 Gesture is a precursor to language**

As noted in section three, the most important consideration for any study of phonology in an artificial language is that it successfully bypass participants' native phonological knowledge. A typical solution has been to use an artificial modality, one that is free of the perceptual biases and articulatory habits that come with knowledge of a language.

But a modality need not be artificial in order to be unfamiliar. The vast majority of people—everyone who does not speak a sign language—have no gestural phonology at all. An artificial language

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<sup>8</sup> Recall that the vertical coordinate decreases at a fixed rate. Even though the images produced are two-dimensional, one of those dimensions is fully deterministic and has no expressive power.

in gesture is just as linguistically novel to them as one on a slide whistle. At the same time, the manual/visual channel is not novel at all in the context of human language more generally. Sign languages prove that it can easily accommodate all the familiar functions of language and surface all the expected cognitive biases. Moreover, unlike in any other modality, newly emerging sign languages provide us the opportunity to watch gesture develop into full-fledged language in real time.

We can never expect to observe a new spoken language emerge. This is because emergence is explicitly distinguished from historical change—the question is what can happen in a community without a language made up of individuals without languages, a situation that is obviously rare in the modern world. It is fundamentally different from a process of creolization, where even in the most idealized situation, members of the founding generation of pidgin-speakers would still each have a native language of their own. There has hardly ever been a single cognitively normal hearing person who grows up without learning a language, much less a whole group of such people who devise a new system together.

This situation, however, is sadly common among deaf people born into communities or regions without an available sign language. If there is no exposure to sign, it is relatively easy for a cognitively completely ordinary child to grow up without any native language at all. Because the base rate of deafness is low, it may often be the case that there is no local sign language to learn or that a child born into a hearing family does not have the opportunity to be educated in the sign language of their country or region. Indeed, there are really two specific situations where signing communities tend to form and therefore sign languages to be used and taught (Meir et al. 2010). One is in the instance where, because of a genetic bottleneck effect, the rate of deafness in a specific isolated place is much higher than in the general population. Because of the high number of deaf individuals in this would-be speech community a sign language develops as an auxiliary to the spoken language of the group, and is used even by hearing individuals (de Vos and Pfau 2015). This is usually referred to as a village sign because the use of that language may be confined to an area as small as a single village. New sign languages may also form at schools for the deaf, since they concentrate many deaf individuals together—in particular children—from what may have been a very dispersed area of origin. The establishment of a school can create a potential speech community where one had not previously existed and is therefore fertile ground for language development (Senghas et al. 1997). In both cases a group of individuals without any alternative native language come under pressure to communicate and, through that communication, form the language they need. When this happens, linguists have

the opportunity to study the transition from ad hoc home sign systems which are communicative but not grammatical languages, to fully elaborated languages over the course several generations.

The best-known ongoing cases of emerging sign languages include one village sign—Al-Sayyid Bedouin Sign Language, or ABSL—and one institutional sign—Nicaraguan Sign Language, or NSL. These cases receive a lot of attention because they have come under linguistic study very early in their histories during the period of rapid elaboration that occurs in the very first few generations of signers. And indeed, with each generation these languages qualitatively increase in complexity, developing, seemingly from nothing, some of the universal features and organizing principles of language that in their more rudimentary phases they had lacked. It should be emphasized that these languages differ from neighboring spoken languages on fundamental grammatical axes, and do not seem to have taken them as raw material to be translated into sign (Senghas 1997, Kocab, Senghas, and Senedeker 2016, Sandler et al. 2005, Nyst 2007). Rather, they represent a gradual process of elaboration on a fundamentally gestural system, where natural gesture is codified into homesign and then grammaticalized into language.

## 5.2 Emerging sign phonology

So, what does phonology look like in a young sign language? I focus here on ABSL, since it has been the subject of the most extensive description relating to this question. Recall from section four for comparison that in established sign languages like ASL, multiple dimensions of each sign (such as handshape or location) function as fixed, contrast-bearing elements.

In ABSL, meanwhile, most of these dimensions have not been given phonological significance. Different individuals giving the same sign in citation form will produce it with variation in the set of selected fingers, the orientation, and the location, to a degree that would be interpreted as contrastive in known older sign languages (Sandler et al. 2011). Signs tend to be distinguished on the basis of handshape alone.<sup>9</sup> Because of this, Sandler et al. conclude that the language as a whole has not yet developed a true phonology. At the same time, they describe individual signers and groups of signers who do display phonological processes—all members of the youngest (third) generation. There

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<sup>9</sup> Even handshape contrast can sometimes be overridden by iconic concerns. For example in the sign for “tea,” all of the elicited forms show the same location, orientation, and movement (a wrist rotation near the mouth that suggests drinking from a cup). But they can vary in handshape, with several distinct forms that mimic different possible grasps. This suggests that even the phonologization of handshape is not yet completed.

are instances of assimilation in compounds, enforced symmetry in formerly iconic signs, and reduction of marked handshapes and orientations. These usages, and the fact that they are occurring in the youngest group, suggest that phonology is on the cusp of emerging in ABSL as a whole and that both individual innovations and generational effects are feeding the process.

Over the course of the first few generations of this language, there is the gradual establishment of phonological patterns and elements—giving credence to the general claim that dual patterning can develop over time and be present to varying degrees, rather than being binary and arriving fully formed in a single leap (Sandler 2017). Relative to older sign languages, we see the various phonetic dimensions of the signal being recruited for phonology as needed, not all at once, with handshape taking priority. At the same time, there is no hint of segmental organization, confirming the necessity of making simultaneous units the basis for future comparisons. To the extent that iterated learning experiments succeed in modeling full language emergence, and not just in inducing a superficially similar-looking process, we should hope to see them display trajectories of phonological development that are similar to, or makes sense in light of, these patterns in natural language.

## **6. Discussion**

Experiments in silent gesture would go a long way in advancing research on duality of patterning and on the relationship of artificial languages to young natural ones. There are two big questions remaining. The first—how can it be done?—is a real problem, though by no means intractable. The second—does this kind of evidence really bear on evolutionary questions?—is urgent and complex. In the end, I believe that the answer is (a qualified) yes, and that comparison of naturally emerging and artificially emerging languages actually strengthens the claims of both in this regard.

### **6.1 Difficulty of implementation**

Experiments in gesture are challenging to implement, and all the more so when the subject is phonology. The very richness of the signal, which makes possible all the simultaneous complexity of sign languages, also makes it very difficult to adequately record, numerically describe, and qualitatively break down the utterances that participants produce. Artificial language experiments in gesture that have been successful in the past tend to look at phenomena like word order and semantic role that do not require such a precise analysis of the articulation of each sign (Goldin-Meadow et al. 2008, Motamedi et al. 2017, Schouwstra 2016). At a minimum, a study of phonology in artificial gestures

would require more sophisticated tools for tracking and recording the position of the hands and body: there is no way to capture with simple video the kinds of subtle regularization that we expect to find in early generations.

The analysis is also more difficult. First, there is the question of which parameters to break out, of all the phonological features that we know a mature sign can contain. And since these gestures will be much more complex to characterize than a short whistled melody, the measurement of their difference and similarity, and the calculation of complexity over the whole lexicon, would all be likewise more involved. Of course none of these are categorical obstacles, but it is true that studying phonology in gesture presents more practical challenges than studying syntax or semantics in gesture or than studying phonology in simpler modalities.

## **6.2 Are new sign languages truly emergent?**

The development of new sign languages is clearly of great interest as an analogy to the development of artificial languages in the laboratory. They provide a naturalistic example of the grammatical changes that accompany generation learning and transmission. But while the natural environment is their greatest strength as a case study, it also introduces inevitable questions about the extent to which these languages are really new.

The most basic is that there is no true linguistic vacuum—emerging signs inevitably have contact with other languages. First, it is not universally true that deaf children fail to learn the spoken language of their family. And even if they personally do not speak it, any homesign that exists is usually also used by the hearing members of the family—village signs, which are elaborated within a community context and used by the hearing as well as the deaf, are by definition in sustained contact with at least one spoken language. This can have the expected grammatical effect: for example, in the village sign of Adamorobe, Ghana, Nyst finds a causative verbal construction that is unlike that of any known sign language but exactly like that of Akan, the primary spoken language of the village (2007). If signers attend school, there may be explicit oralist education in the national language. This was originally the case in the Managua school where NSL emerged (Kocab, Senghas, and Senedeker 2016). Even schools that embrace sign language may also teach literacy in a national language, which creates another, though lesser, point of contact.

Another potential problem<sup>10</sup> is contact with other existing sign languages. This can happen through the arrival of educational or humanitarian workers or through integration with a larger deaf community. In Nicaragua, for example, there has been some contact with ASL since 1974 through the programs of the Gallaudet Regional Resource Program on Deafness and with Swedish Sign Language through the programs of the Swedish Federation of the Deaf (Delkamiller 2013). This type of contact can alter the language both in that newcomers may directly teach locals signs or structures from their own native language, and in that as L2 learners of the local sign they may bring in structures from their native languages. Village signs may also be subject to contact with a national sign language, if one exists. The so-called “third generation” of ABSL signers are being educated at a nearby school where ISL is used (Israel and Sandler 2011).

More fundamentally, even a completely novel modern sign language uninfluenced by contact would not be a true cognitive novelty in the way that an original transitional linguistic system would have been. Although our primary focus has been on the transition in a language system itself from prelinguistic to fully elaborated, this obviously does not mean ignoring the fact that language is instantiated in the minds of individual speakers. Those minds have their own characteristics which are not static over evolutionary time. Even if they have no other native language, the creators of emerging signs are fully endowed with the cognitive equipment that underlies the learning and use of all modern languages. If there are any specific typological choices, “design features,” learning algorithms, or grammatical axioms that are hardwired into all people, they are also hardwired into these speakers and therefore are only emergent in the context of a specific speech community and not in the deepest sense. This, of course, is all the more true of participants in laboratory experiments who have native competence in their spoken language as well innate capacities.

However, the strongest reading of this argument—that *all* the new grammar that emerges in new languages is merely the deterministic surfacing of innate knowledge—is not actually in line with what we observe. It is precisely because early generations of emergent signs—even those which are being used by native speakers, i.e. the second generation in ABSL or the middle cohort in NSL—do not fully conform to linguistic universals that they are of interest. The strong reading for “superficial emergence” is somewhat at a loss to explain the multigenerational timeframe over which these features eventually develop. In the claim that all this new structure is deriving from the preexisting cognitive architecture of individuals, there is not much room for a normal native child learner who acquires an

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<sup>10</sup> For the analysis, not for the speakers!

intermediate grammar, more complex than the one she was exposed to but still violating broad universals. The fact that multiple generations effect this process cumulatively indicates that something more than the purely individual is at work. On this score, emergent sign languages are not just a good point of comparison, but actually help to validate the theory behind iterated learning experiments and support the idea that their findings are not solely the result of peering into a finished modern language module.<sup>11</sup>

## 7. Conclusion

A full comparison with emerging sign languages has the potential to enrich experimental models in every way. They provide an example of what is possible, a check on what is unlikely, and a naturalistic validation of the very concept of incremental development of universal grammatical forms. Since we can't change what is naturally occurring, the only way to bring these two areas of research into closer harmony is to change the experiments. Iterated learning in gesture is a promising next step towards understanding the emergence of dual patterning and moving beyond the limitations of artificial modalities. If such experiments can accurately model what is seen in emerging signs, it would confirm that they are not merely creating something plausible, but observing something real.

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<sup>11</sup> Though even this is hardly a fatal criticism—it would be quite worthwhile to learn something about the contents of that innate knowledge.



## References

- Armstrong, David. 1983. Iconicity, arbitrariness, and duality of patterning in signed and spoken language: Perspectives on language evolution. *Sign Language Studies* 38. 51-69.
- Aronoff, Mark, Irit Meir, Carol Padden & Wendy Sandler. 2008. The roots of linguistic organization in a new language. In: Derek Bickerton and Michael Arbib (eds.) *Holophrasis, Compositionality and Protolanguage*, Special Issue of *Interaction Studies*. 133-149.
- Aronoff, Mark, Irit Meir & Wendy Sandler. 2005. The paradox of sign language morphology. *Language* 81(2). 301–344.
- Blevins, Juliette. 2012. Duality of patterning: Absolute universal or statistical tendency? In Bart de Boer, Simon Kirby, and Wendy Sandler (eds.), *Language and Cognition* 4(4).
- de Boer, Bart. 2005. Cultural and Biological Evolution of Phonemic Speech. In Mathieu Capcarrère et al. (eds.) *European Conference on Artificial Life*. 614-623.
- de Boer, Bart & Willem Zuidema. 2010. Multi-agent simulations of the evolution of combinatorial phonology. *Adaptive Behavior* 18(2). 141-154.
- Brentari, Diane, Marie Coppola, Laura Mazzoni & Susan Goldin-Meadow. 2012. When does a system become phonological? Handshape production in gesturers, signers, and homesigners. *Natural Language & Linguistic Theory* 30(1). 1–31
- Brentari, Diane & Petra Eccarius. 2009. A formal analysis of phonological contrast in sign language handshapes. In *Proceedings from the European Summer School for Language, Logic, and Information (ESSLLI)*.
- Brentari, Diane, & Petra Eccarius. 2011. When does a system become phonological? Potential sources of handshape contrast in sign languages. In Harry van der Hulst and Rachel Channon (eds.) *Formational units in sign languages*. 125-150.
- Brentari, Diane, Jordan Fenlon & Kearsy Cormier. 2018. Sign Language Phonology. Oxford Research Encyclopedia of Linguistics.
- Brentari, Diane & Susan Goldin-Meadow. 2017. Language Emergence. *Annual Review of Linguistics* 3. 363-388.
- Carr, Jon, Kenny Smith, Hannah Cornish & Simon Kirby. 2017. The cultural evolution of structured languages in an open-ended, continuous world. *Cognitive Science* 41. 892-923.
- Channon, Rachel. 2002. *Signs are single segments: Phonological representations and temporal sequencing in ASL and other sign languages*. College Park, MD: University of Maryland dissertation.
- Christiansen, Morten & Simon Kirby. 2003. Language evolution: The hardest problem in science? In Morten Christiansen and Simon Kirby (eds.) *Language Evolution*. 1-15. New York: Oxford University Press.

- Christiansen, Morten & Simon Kirby. 2003. From language learning to language evolution. In Morten Christiansen and Simon Kirby (eds.) *Language Evolution*. 272-294. New York: Oxford University Press.
- Emmorey, Karen. 2002. *Language, Cognition, and the Brain: Insights from Sign Language Research*. New York: Psychology Press.
- Fay, Nicolas & Mark Ellison. 2013. The cultural evolution of human communication systems in different sized populations. *PLoS ONE* 8(8).
- Del Giudice, Alex. 2012. The emergence of duality of patterning through iterated learning: Precursors to phonology in a visual lexicon. *Language and Cognition* 4(4).
- Goldin-Meadow, Susan, Wing Chi So, Aslı Özyürek & Carolyn Mylander. 2008. The natural order of events: How speakers of different languages represent events nonverbally. *Proceedings of the National Academy of Sciences*, 105(27). 9163-9168.
- Hauser, Marc, Noam Chomsky & W. Tecumseh Fitch. 2002. The faculty of language: what is it, who has it, and how did it evolve? *Science* 298(5598). 1569-1579.
- Hockett, Charles. 1960. The Origin of Speech, *Scientific American* 203, 88–111 Reprinted in Wang, William. 1982. *Human Communication: Language and Its Psychobiological Bases*. 4–12
- van der Hulst, Harry. 1993. Units in the analysis of signs. *Phonology*, 10(2). 209-241.
- Israel, Assaf, & Wendy Sandler. 2011. Phonological category resolution in a new sign language: A comparative study of handshapes. In Harry van der Hulst and Rachel Channon (eds.) *Formational units in sign languages*. 177-202.
- Kirby, Simon. 1999. *Function, selection, and innateness: the emergence of language universals*. Oxford: Oxford University Press.
- Kirby, Simon, Hannah Cornish & Kenny Smith. 2008. Cumulative cultural evolution in the laboratory: An experimental approach to the origins of structure in human language. *National Academy of Sciences* 105(31).
- Kirby, Simon, Tom Griffiths & Kenny Smith. 2014. Iterated learning and the evolution of language. *Current Opinion in Neurobiology*, 28. 108–114.
- Kirby, Simon, Monica Tamariz, Hannah Cornish & Kenny Smith. 2015. Compression and communication in the cultural evolution of linguistic structure. *Cognition* 141. 87-102.
- Kocab, Annemarie, Ann Senghas & Jesse Snedeker. 2016. The emergence of temporal language in Nicaraguan Sign Language. *Cognition* 156. 147–163
- Ladd, D. Robert. 2012. What *is* duality of patterning, anyway? *Language and Cognition* 4(4). 261-273.

- Liddell, Scott. 1984. THINK and BELIEVE: sequentiality in American Sign Language. *Language* 6(2). 372-399.
- Martinet, André. 1960. *Eléments De Linguistique Générale*. Paris: Armand Collin.
- Meir, Irit, Wendy Sandler, Carol Padden & Mark Aronoff. 2003. Emerging Sign Languages. *Oxford Handbook of Deaf Studies, Language, and Education, Volume 2*. New York: Oxford University Press.
- Motamedi, Yasamin, Marieke Schouwstra, Jennifer Culbertson, Kenny Smith & Simon Kirby. 2017. The cultural evolution of complex linguistic constructions in artificial sign languages. 39th Annual Conference of the Cognitive Science Society. 2760-2765.
- Motamedi, Yasamin, Marieke Schouwstra & Simon Kirby. 2017. An evolutionary approach to sign language emergence. *Behavioral and Brain Sciences*, 40. 35-36.
- Newmeyer, Frederick. 2003. What can the field of linguistics tell us about the origins of language? In Morten Christiansen and Simon Kirby (eds.) *Language Evolution*. 58-76. New York: Oxford University Press.
- Nyst, Victoria. 2007. A Descriptive Analysis of Adamorobe Sign Language (Ghana). Amsterdam: University of Amsterdam dissertation.
- Roberts, Gareth & Bruno Galantuci. 2012. The emergence of duality of patterning: Insights from the laboratory. *Language and Cognition* 4(4).
- Sandler, Wendy. 2010. The uniformity and diversity of language: Evidence from sign language. *Lingua*, 120(12). 2727-2732.
- Sandler, Wendy. 2012. The phonological organization of sign languages. *Language and Linguistics Compass*. 162-182.
- Sandler, Wendy. 2017. The challenge of sign language phonology. *Annual review of Linguistics* 3. 43-63.
- Sandler, Wendy, Mark Aronoff, Irit Meir & Carol Padden. 2011. The gradual emergence of phonological form in a new language. *Natural Language & Linguistic Theory*, 29(2), 503–543
- Sandler, Wendy & Lillo-Martin, Diane. 2006. *Sign Language and Linguistic Universals*. Cambridge: Cambridge University Press.
- Sandler, Wendy, Irit Meir, Carol Padden & Mark Aronoff. 2005. The emergence of grammar in a new sign language. *Proceedings of the National Academy of Sciences*, 102(7). 2661-2665.
- Schouwstra, Marieke. 2017. Temporal structure in emerging language: From natural data to silent gesture. *Cognitive Science* 41. 928-940.

- Schouwstra, Marieke, Simon Kirby & Jennifer Culbertson. 2017. Silent gesture and noun phrase universals. 39th Annual Conference of the Cognitive Science Society. 3095-3100.
- Senghas, Ann, Marie Coppola, Elissa Newport & Ted Supalla. 1997. Argument structure in Nicaraguan Sign Language: The emergence of grammatical devices. E. Hughes, M. Hughes, and A. Greenhill (eds.), Boston University Conference on Language Development, 21(2), 550-61. Boston, MA: Cascadilla Press.
- Senghas, Ann, Sotaro Kita, & Asli Özyürek. 2004. Children creating core properties of language: Evidence from an emerging sign language in Nicaragua. *Science*, 305(5691). 1779–1782.
- Silvey, Catriona, Simon Kirby & Kenny Smith. 2013. Word meanings evolve to selectively preserve distinctions on salient dimensions. *Cognitive Science* 39. 212-226.
- Smith, Kenny. 2011. Learning bias, cultural evolution of language, and the biological evolution of the language faculty. *Human Biology* 83(2). 261-278.
- Smith, Kenny. 2018. The cognitive prerequisites for language: insights from iterated learning. *Current Opinion in Behavioral Sciences* 21. 154-160.
- Stokoe, William. 1960. Sign language structure: An outline of the visual communication systems of the American deaf. *Journal of Deaf Studies and Deaf Education*, 10(1). 3–37
- Studdert-Kennedy, Michael. 2005. How did language go discrete? In Maggie Tallerman (ed.) *Language Origins*. 48-67. New York: Oxford University Press.
- Tonkes, Bradley & Janet Wiles. 2002. Methodological issues in simulating the emergence of language. In Alison Wray (ed.) *The Transition to Language*. 226-251. New York: Oxford University Press.
- Verhoef, Tessa. 2012. The origins of duality of patterning in artificial whistled languages. *Language and Cognition* 4(4). 357–380.
- Verhoef, Tessa, Simon Kirby & Bart de Boer. 2016. Iconicity and the emergence of combinatorial structure in language. *Cognitive Science* 40. 1969-1994.
- de Vos, Connie & Roland Pfau. 2015. Sign language typology: the contribution of rural sign languages. *Annual Review of Linguistics* 1. 265-288.
- Wray, Allison. 2002. Dual processing in protolanguage: performance without competence. In Allison Wray (ed.), *The Transition to Language*. 113-137. New York: Oxford University Press.