Experimental Studies on the Cultural Evolution of Language

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Abstract

Why are languages the way they are? The biases and constraints that explain why languages display the traits they do—instead of other possible ones—include human cognition, social dynamics, communicative function, the structure of meanings, and the interactions between these. Cultural language evolution is concerned with explaining the causal pathways that link these biases and constraints with fundamental linguistic traits, such as combinatoriality, compositionality, conventionality, and arbitrariness. The cultural evolution of language, or the emergence of a language from no language, begins when motivated signals are used in context by individuals who do not share a means of communication. Repeated interaction between interlocutors makes individual signals compressible through reduction or simplification and can entrench idiosyncratic patterns. Transmission to new learners results in the increasing compressibility at the level of the system through the introduction of categories and regular rules, and in the spread of conventional, arbitrary signals.

1. INTRODUCTION

Language is one of the defining capacities of our species, and its origin and evolution have intrigued scholars for centuries. Linguistic structure displays an impressive diversity across world languages, yet some types of structure are much more common than others. A comprehensive explanation of why humans have language and why languages are the way they are must include an evolutionary perspective (Christiansen & Kirby 2003, Christiansen & Chater 2008, Evans & Levinson 2009).

1.1. Language Change, Cultural Language Evolution, and Biological Language Evolution

The term language evolution is used in at least three different ways (Tamariz & Kirby 2016). First, it may refer to historical or diachronic language change, or the study of changes observed in traits of languages over historical time. Second, it may mean what is termed here cultural language evolution, the focus of this review, which looks at the emergence of linguistic properties from the interplay between modern human cognition and social processes related to learning and usage (Smith & Kirby 2008), and shares key assumptions, theories, and methods with the field of cultural evolution (Boyd & Richerson 1985, Richerson & Boyd 2005, Mesoudi 2011). And third, it may denote the biological evolution of language, which considers the genetic, anatomical, and cognitive evolution of the human capabilities underpinning language learning and use; this is studied by paleontologists, biologists, and comparative psychologists, among others, who examine the existing variation in modern humans, analyze the fossil record of our direct ancestors, and draw comparisons between the communicative and social–cognitive skills of humans and closely related primate species, as well as other species.

The three aspects of language evolution are intimately related, and a full explanation of how language originated and diversified should take all of them into account. Cultural language evolution and language change are supported by the same mechanisms, including learning, processing, and production, which allow us to culturally inherit and socially use language. Evolutionary approaches to language change explain synchronic variation in linguistic structure as the result of diachronic processes, and draw on population thinking, Darwinian dynamics, and complex adaptive systems (Nettle 1999; Croft 2000; Mufwene 2001, 2008; Ritt 2004; Blevins 2004; Wedel 2006, 2011; Altmann et al. 2011). Notwithstanding the effects of drift, the study of cultural language evolution often focuses on adaptive processes to support its central tenet that language structure is the result of adaptation to multiple, varied, and often opposed selective pressures (Beckner et al. 2009). Such complex patterns of adaptation operating at the level of local interactions between interlocutors are reflected, at the level of whole populations, in observed patterns of typological variation such as those proposed by Greenberg (1963) (e.g., Culbertson et al. 2012).

The frontier between language change and cultural language evolution is sometimes tenuous. One possible way to distinguish between them is to ascribe to historical language change those changes whose departing point is a full-fledged language and to ascribe to cultural language evolution those changes that entail the emergence of key properties of language, and therefore contribute to transforming another type of communication system into a full-fledged language (Tamariz & Kirby 2016). In the case of historical language change, the initial and final systems have already undergone cultural language evolution, and are adapted to the biases posed by social processes; with respect to these processes, the languages simply move between highly adaptive states. In cultural language evolution, by contrast, the initial state may be one in which normal cultural transmission is disrupted—for example, when high levels of contact between speaker communities lead to the creation of a pidgin language (McWhorter 2007, Trudgill 2011), or when deaf children raised without linguistic input become homesigners (Goldin-Meadow 2003). This initial state has yet to adapt to the social–cognitive pressures originating in transmission and use in a community of speakers.

The explanations offered by cultural language evolution and language change do not normally involve biological evolution, and typically assume uniformity of (cognitive) process (Newmeyer 2002). In order to understand how modern cognition arose, we must also invoke biological evolutionary processes and gene–culture coevolution (Levinson & Dediu 2013). Human neural connectivity, our speech-producing organs, and our cognitive and behavioral biases probably coevolved with language over the history of our species. Genes that enhanced any incipient communicative and symbolic traits in our ancestors would have been favored by natural selection. In response to the subsequent spread of these genes in the population, we would expect an enhancement of the symbolic and communicative behavior, which in turn would pose further selection for the relevant genes (Deacon 1997, Dor & Jablonka 2014). For overviews of language evolution that include biological processes, see, for instance, Deacon (1997), Johansson (2005), Fitch (2010), Dor et al. (2014), or Scott-Phillips (2014).

This review focuses on the cultural evolution of language, which abstracts away biological evolution and aims to explain the emergence of fundamental features of language (including combinatoriality, conventionality, expressivity, arbitrariness, and compositionality; Hockett 1960) from purely social and cultural factors, such as language learning, communicative usage, social network structure, and properties of the meanings communicated.

1.2. Methods in Cultural Language Evolution

Cultural language evolution researchers use three complementary methods—fieldwork yielding corpora and language surveys, computer modeling, and laboratory experiments. Fieldwork provides a window onto the distribution of features within and across languages; patterns of typological variation have been explained by factors such as genetic differences (Dediu & Ladd 2007), phylogenetic relationships between languages (Dunn et al. 2011), cognitive and communicative pressures (Piantadosi et al. 2011, Regier et al. 2015), and the composition of the population (Lupyan & Dale 2010).

Computer simulations and formal mathematical models can include simulated agents that learn a language or communicate among themselves, or equations that model transmission and communication processes (Kirby 2001, Brighton et al. 2005, Baxter et al. 2006, Kirby et al. 2007, Jaeger et al. 2009, Steels 2011). Models offer the possibility of turning cognitive capacities and social processes on and off, as well as modeling large populations or multiple generations, which is impractical or impossible in experiments.

This article focuses on the third method. It reviews studies reporting experiments with human participants (although experiments with other primates and even birds have also shed light on cultural linguistic questions; e.g., Fehér et al. 2009, Claidière et al. 2014b). The hypotheses tested concern the effects of social and cognitive processes on the emergence of language traits, and ultimately on the typological distribution of variants observed in world languages. The following sections describe experiments that show how language becomes more compressible, expressive, and learnable as it is used and transmitted to new learners, and how its structure adapts to cognitive biases, to properties of the population, to the communicative context, and to meanings. The adaptive traits of language that emerge under these constraints include expressivity, conventionality, arbitrariness, combinatoriality, and compositionality.

The rest of this review is structured as follows. Section 2 describes in detail two seminal experiments that illustrate the main questions and techniques in the field of cultural language evolution. Sections 3 and 4 review studies that explore the effects of communicative function and transmission to new learners, respectively, on language structure. Section 5 presents some debates in the field, and outlines possible future avenues for experimental research.

2. SEMINAL EXPERIMENTAL STUDIES

Much experimental research in the cultural evolution of language has its origins in two pioneering experimental designs used to address distinct questions (**Figure 1** gives an overview of designs in this field). Garrod et al.'s (2007) experimental semiotics approach focuses on the emergence of new conventions during communicative interactions between interlocutors and analyzes the semiotic status of those conventions (Galantucci & Garrod 2010, 2011). Kirby et al.'s (2008) iterated learning approach is more concerned with the effects of transmission on the emergence of structural features of language, such as regularity and compositionality; it relies on the capacity of transmission chains to reveal and amplify transmission biases (Scott-Phillips & Kirby 2010, Kirby et al. 2014, Tamariz & Kirby 2016). In subsequent studies, the two approaches have been combined in many novel and interesting ways.

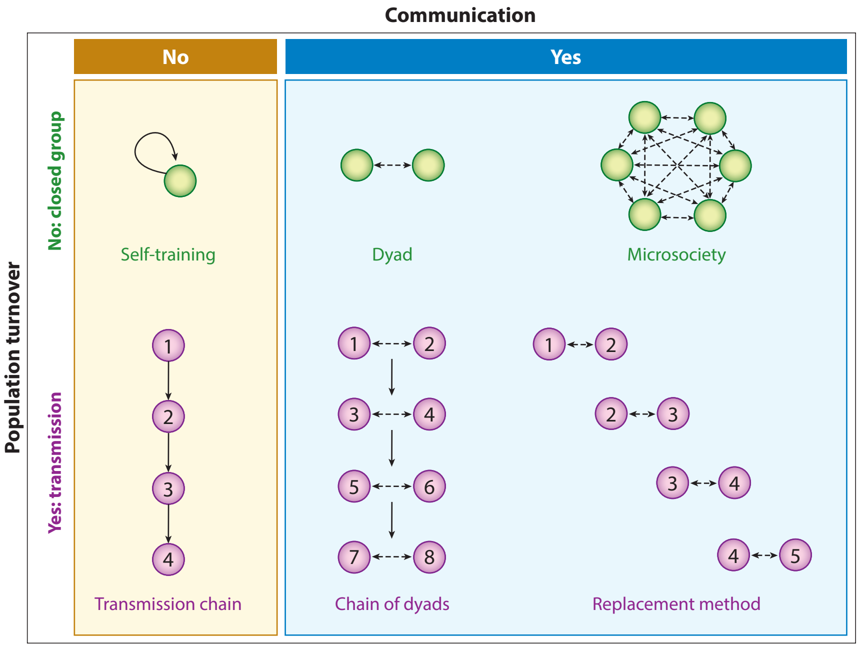

Figure 1

Population dynamics in cultural language evolution experiments. Dashed lines indicate communicative interaction; solid lines indicate transmission to new speakers. (*Top*, *green*) In closed groups, the population is constant. In self-training designs, a participant produces or is given a pattern, which she then reproduces repeatedly over experimental rounds. In microsocieties (of varying size; the smallest has only two members and is called a dyad), subsets of members communicate with one another. (*Bottom*, *purple*) In transmission conditions, the composition of the population changes over time. Transmission chains involve a number of generations, each of which receives outputs produced by the previous one. In chains of dyads—or in chains of microsocieties—members of each generation also communicate with one another. In the replacement method, a number of participants interact (e.g., communicate, teach, learn), and at each round, one is removed and a new one is added. See also Mesoudi & Whiten (2008).

2.1. The Emergence of Simple, Conventional Signals During Communication

Natural languages are mostly arbitrary [de Saussure 1983 (1916), but see, e.g., Monaghan et al. 2014, Dingemanse et al. 2015]. However, the initial signals improvised by interlocutors who do not share a communication system usually have an iconic or indexical motivation. Garrod et al. (2007) used a communication task to test the hypothesis that, over repeated communicative usage, improvised iconic signals would gradually become arbitrary. In their influential experiments, participant dyads (**Figure 1**) played a naming game based on Pictionary; one of the players—the director—was presented with a target concept (out of an array of 16, including 'Robert de Niro,' 'soap opera,' and 'microwave'), and he had to produce a drawing that would allow the other player—the matcher—to select the correct target out of the 16. In each trial, the matcher waited until the director had finished drawing before making his guess. They went through several blocks of play, each including 12 of the 16 concepts, so each concept was communicated several times. The experiment included three conditions designed to investigate how feedback between the two players and swapping the director and matcher roles affected the evolution of the communication system, with a particular interest in the emergence of arbitrariness. In the single-director-no-feedback condition, the same participant played the role of director throughout the experiment, and there was no communication between the players other than the director's drawing. In the single-director-with-feedback condition, after the matcher had made his selection, he could go to the board and give graphical feedback, for instance, by marking it with a tick if he had understood or by annotating or modifying the director's drawing, to which the director could answer with further modifications until the matcher was happy he had understood. Finally, the double-director-with-feedback condition was like the single-director-with-feedback condition, but the two participants alternated the roles of director and matcher.

The results led to several interesting observations. First, the communicative success (the proportion of trials when the matcher selected the correct meaning) improved over rounds in all conditions, but more so when there was feedback. Second, the dyads converged on the same set of signals (through interactive alignment; e.g., Pickering & Garrod 2004). Third, the graphical complexity of the drawings responded to the manipulation in a surprising way: In the feedback conditions, the drawings became increasingly simple over time—for example, the signal for 'cartoon' in one of the dyads evolved from an initial elaborate drawing of Bugs Bunny and Daffy Duck to a final drawing of rabbit ears. This process was explained as a migration of information from the external, graphical representations to the interlocutors' minds as common ground accumulated. In the no-feedback condition, however, the drawings actually grew more complex over rounds of the game. This ruled out an explanation of the simplification of the signals based on mere repetition, and instead supported the hypothesis that feedback between interlocutors and alternation of the director and matcher roles help ground the signals—that is, entrench the signal–meaning associations for both players. Each production of a graphical representation of a concept can thus be a slightly simpler version of the already-grounded previous drawing, and still be understood.

Garrod et al. (2007) then had naïve observers attempt to match each of the drawings produced in the previous study to 1 of the 16 concepts. The results of this task also produced interesting findings. First, the observers' accuracy was lower than the accuracy of the matchers during the game; second, observers who saw the drawings produced in all six rounds were more accurate in identifying the target concept than those who saw the drawings from the last three rounds only. The low identification rates were interpreted as evidence for the increasing symbolicity of the drawings over rounds: The earlier drawings were easy to interpret because they were iconic, but the later ones were not because they had become arbitrary.

Arguably, for the players who produced and used the signals (and, to some extent, for the observers who saw drawings from all rounds of play), the simple drawings produced in round six were still iconic, as they knew about the motivated association between drawing and meaning (Brown 2012). It would take a new naïve learner for the signs to be truly arbitrary, as he or she would have no inkling of the original iconicity. Caldwell & Smith (2012) confirmed that simple, nonmotivated signals can indeed be learned and used successfully in a replacement method chain (**Figure 1**). As old speakers gradually left and new ones joined, the authors obtained a population that had learned and used a fully arbitrary set of signs.

2.2. The Emergence of Systematic Linguistic Structure over Transmission to New Learners

An early computer simulation of language evolution suggested that linguistic systematic structure could be the result of mere repeated learning and reproduction of a language (Kirby 2001). To test whether this prediction held when the learners were real humans, Kirby et al. (2008) conducted the first modern iterated learning experiment [early antecedents include Bartlett's (1932) renowned serial reproduction experiments and experiments by, for instance, Esper (1925) and Wolfle (1933)]. Kirby et al. (2008) trained human adults with artificial miniature languages and then tested them for recall, in a transmission chain (**Figure 1**). The languages consisted of random nonce signals paired with objects (the 27 objects in **Figure 2*a***). Half of the signal–object pairs in the language were randomly selected and used to train the participant in the first generation of the chain by displaying in turn each object and its corresponding (written) signal on a computer screen. This was repeated throughout six rounds of training. During testing, the participant was presented with all 27 objects, one at a time, and had to type the appropriate signal. Although half of the testing objects had not been seen during training, few participants reported noticing that there were unseen items. Half of the signal–object pairs produced were randomly selected to train the next participant in the transmission chain.

As they were learned and reproduced for 10 generations in this iterated fashion, the languages accumulated interesting properties. Final languages were more accurately learned and reproduced than initial languages; they were also more systematically structured. By generation 10, objects that shared features had signals that were more similar than expected by chance. As clearly shown in **Figure 2*a***, this was the result of languages becoming simpler. A language could end up with very few distinct signals, which invariably co-occurred with one or more of the meaning dimensions; for instance, the language in **Figure 2*a*** can distinguish the objects' motion and, only for circular motion, distinguish triangles from the other two shapes. The authors concluded that the languages adapted to iterated learning by becoming easy to reproduce accurately. Following the superficially tautological logic that underlies selection evolutionary processes, the easier-to-transmit features of the languages were transmitted preferentially, and thus tended to persist over time and spread to the unseen signal–object mappings.

The descriptions of these studies reveal a number of factors influencing different aspects of language structure. **Figure 3** summarizes some causal pathways behind the emergence and maintenance of linguistic features.

3. COMMUNICATING MEANING

Communication places several pressures on the structure of languages, and languages, in response, adapt to optimize communication (Regier et al. 2015). A central aim of communication is disambiguation in context, to which language responds by having distinct signals for different meanings.

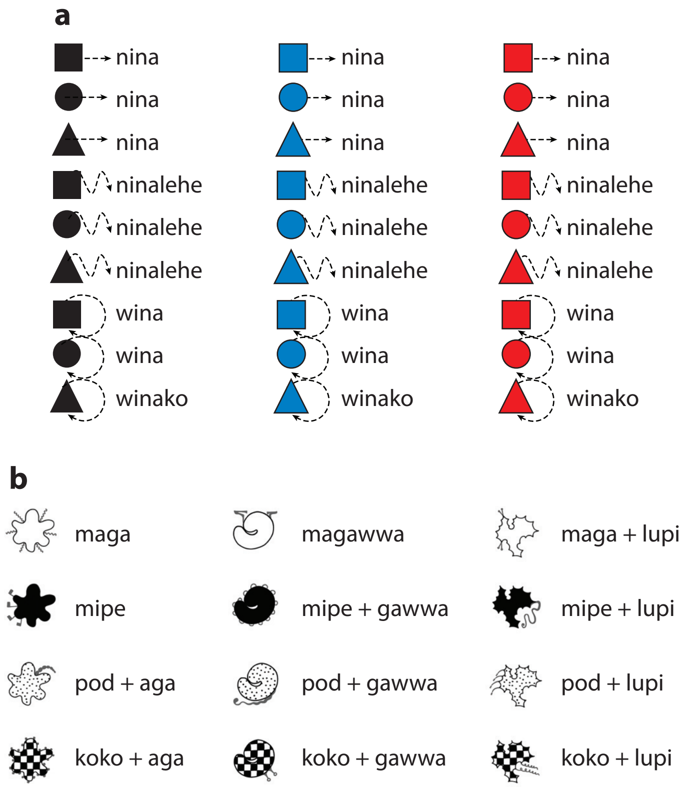

Figure 2

Languages produced in the last generation of (*a*) experiment 1 from Kirby et al. (2008), displaying systematic underspecification, and (*b*) the chain-of-dyads condition from Kirby et al. (2015), displaying compositionality (labels are segmented in the figure to illustrate this property). Modified from data in the original papers.

Although linguistic signs are largely arbitrary [de Saussure 1983 (1916)], the structure of meaning nonetheless influences language structure in several ways. The following subsections review experimental studies exploring the cultural mechanisms behind these effects.

3.1. The Need for Disambiguation Drives Expressivity

In order to be efficient for communication, a language needs to be able to unambiguously map signals to meanings. The communication systems described by Garrod et al. (2007) are fully expressive in this sense, as there is a signal for each meaning. Underspecified languages like those produced in the Kirby et al. (2008) study, however, are not; the language in **Figure 2*a***, for instance, does not have a signal to designate the horizontally moving blue circle unambiguously. To investigate the origin of linguistic expressivity, Kirby et al. (2015) combined transmission and communication in a chain-of-dyads design (**Figure 1**). Pairs of participants were trained on all the items in a miniature language and subsequently played a communication game similar to the one of Garrod et al. (2007). The signals produced for each object by one of the participants selected at random were used to train the next pair in the chain. Over six generations, and under simultaneous pressure from transmission and communication, the languages evolved a new property: compositionality (**Figure 2*b***). The final languages, similar to those of Kirby et al. (2008), were

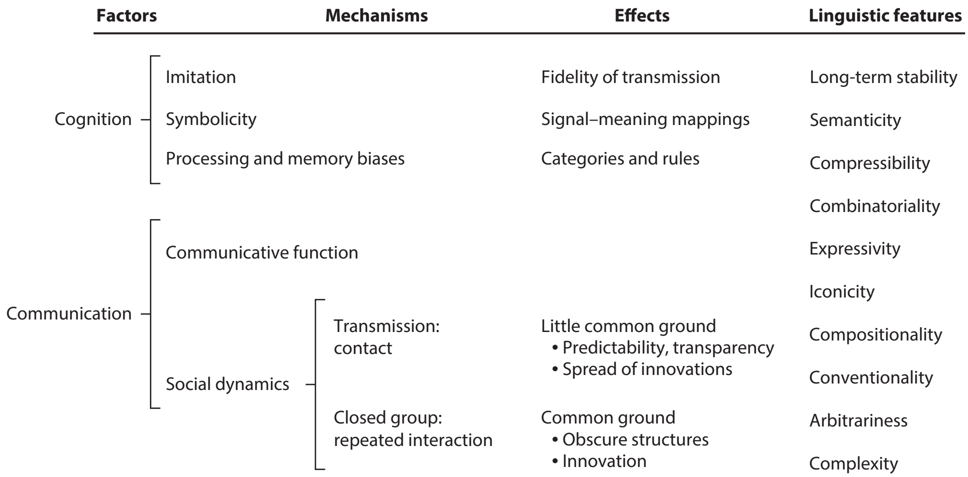

Figure 3

Diagram showing the main causal relationships between cultural–evolutionary factors/mechanisms and aspects of linguistic structure. Additional relationships, not shown in the figure for the sake of simplicity, are also at work. For example, cognitive factors and communication are involved in the emergence of all linguistic features, and communicative function is present in both transmission and closed-group interaction.

more accurately reproduced and more systematically structured than the initial ones. Additionally, they had become expressive: They had a distinct signal for each object. Theisen et al. (2010) and Theisen-White et al. (2012) obtained similar results by using drawings instead of words to name the meanings. Kirby et al. (2015) included an additional dyad condition (**Figure 1**) in which the same pairs of participants, instead of fresh pairs, underwent the training and playing regime described above. The final languages were fully expressive, with an idiosyncratic signal for each object (similar to proper nouns), but they did not show systematic structure.

3.2. The Role of the Communicative Context

Natural languages contain synonymy and homonymy, which make them theoretically less than fully expressive. In these cases, the context may play a role: If two concepts are used in distinct contexts, such as 'bank (of a river)' and 'bank (money),' they can be referred to by the same signal, and the context alone disambiguates the meaning. Winters et al. (2015) investigated the effects of context on linguistic structure by using a miniature artificial language that referred to a series of objects of different shapes and, crucially, included homonymy: three different signals for each object. They used a chain-of-dyads design (**Figure 1**) similar to that of Kirby et al. (2015). During communication, the players saw two objects: a target and a distractor. The director named the target, and the matcher had to guess which of the objects it referred to. The researchers manipulated the composition of the target–distractor pairs in one of three ways: The pairs always had the same shape (and therefore naming the shape did not help discrimination); the pairs always had a different shape (and therefore shape consistently helped discrimination); or same and different pairs were mixed. As predicted, all languages eliminated homonymy, thus increasing their predictability (and decreasing their entropy) over generations. Additionally, the signals in the same-shape condition were idiosyncratic; those in the different-shape condition were underspecified, encoding only shape; and those in the mixed condition became compositional, specifying both shape and individual features.

In a similar study, this time in a transmission chain (**Figure 1**), Silvey et al. (2015) found that, even in the absence of a communicative task, languages can become underspecified by losing contrasts that are irrelevant to disambiguation between target and distractor in context. Interestingly, Hartmann et al. (2016) manipulated the context to reveal the emergence of overspecification. An initially optional semantic marker became obligatory even when it was irrelevant for disambiguation over transmission chains. This was explained as a strategy that simplifies the task for speakers, who do not need to decide each time whether to apply the rule. Taken together, these experimental models present convincing evidence of the adaptation of language structure to the contextual niche.

3.3. Adaptation to the Meaning Space

Another important aspect of the environment where language evolves, and which therefore places selection pressures on linguistic structure, is meaning structure. In the experiment by Garrod et al. (2007), for instance, graphical signals resembled the concepts they iconically referred to. Fay et al. (2010) used the same task as Garrod et al. (2007) to examine the spread of graphical signals in a microsociety (**Figure 1**). They found that certain drawings, which tended to be particularly efficient or perceived as clever, such as a very simple line drawing of a pit to signify 'Brad Pitt,' spread to the whole population, whereas others were abandoned. This study also illustrates experimentally how local processes, operating during pairwise interactions, can lead to the establishment of global conventions at the level of the population. Tamariz et al. (2014) demonstrated that the patterns of spread of drawing variants were not random, but consistent with selection dynamics. Some variants were "fitter"—a better match—than others as representations of a given concept, and they were preferentially adopted and reproduced.

The graphical medium used in these studies (as well as other media, such as gesture) is well suited to iconic reference, compared with the vocal medium that supports most linguistic communication (Fay et al. 2013, 2014; but see Perlman et al. 2015). Roberts et al. (2015) investigated the effects of the iconic match between meanings and the representation medium. Their participant dyads (**Figure 1**) used a digital writing pad that distorted the signals written on it (first used in Galantucci 2005) to communicate either about lines, which were easy to represent iconically in the pad, or about shades of green, which were hard to represent. The signals for the lines evolved to be more iconic, complex, and efficient for communication than the signals for the colors. The latter became combinatorial, with a few graphical units recombined in different ways to denote the different shades of green (Roberts et al. 2015). Further limitations to opportunity for iconicity, such as signals that fade rapidly from view, boost combinatoriality (Galantucci et al. 2010). Combinatorial systems are compressible because they can be described as a finite number of elements (e.g., phonemes, morphemes) and the rules to combine them, instead of a distinct element for each meaning (e.g., words, sentences). Like compositionality, combinatoriality is an adaptation of systems to facilitate processing and reproduction. This effect is not exclusive to language; repeatedly transmitted nonlinguistic stimuli, such as sets of sound patterns (Verhoef 2012, Verhoef et al. 2014), of color sequences (Cornish et al. 2013), and of animal silhouettes (Roberts & Galantucci 2012), also evolve combinatoriality.

When sets of meanings are organized into categories, motivated signal–meaning relationships can occur at a higher level in the form of systematicity (see Dingemanse et al. 2015 for definitions of iconicity and systematicity). Signals can then denote category-defining properties of meanings, rather than individual meanings. Perfors & Navarro (2014) tested whether artificial languages adapted to the meaning category structure. They constructed two meaning spaces that highlighted either size or color distinctions (**Figure 4**). After 10 generations in a transmission chain paradigm

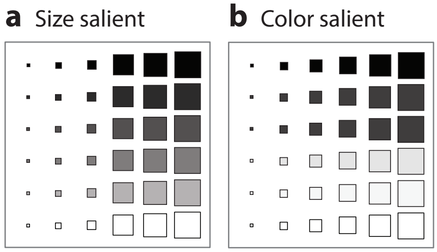

Figure 4

Manipulation of the meaning space with a salient discontinuity in (*a*) size and (*b*) color. Modified from Perfors & Navarro (2014).

similar to that of Kirby et al. (2008), the resulting underspecified languages encoded the salient distinction in each condition, whereas nonsalient distinction tended to disappear: Languages in the size-salient condition evolved words for large and small, but in the color-salient condition they evolved words for dark and light.

Other studies have examined cultural language evolution in continuous meaning spaces, in which category boundaries are not specified. Silvey et al. (2013) and Xu et al. (2013) studied the emergence of categories in quasi-continuous meaning spaces: morphed polygons and colors. Xu et al. (2013) ran transmission chains (**Figure 1**) in which the initial participant was trained with an "unnatural" color-term system, where each signal referred to a random set of six unrelated colors. After training, they had to name 330 different color chips. A random subset of these signal–color pairs was used as the training set for the next participant in the chain. After 13 such generations, each signal designated not a random set of colors but a distinct, convex region of the color space (in a convex space, for any two members of a category, all members situated between them also fall into that category; Gärdenfors 2000). Moreover, the partitions of the color continuum reflected typologically frequent patterns (Regier et al. 2007). This observation indicates that these artificial experimental languages adapted to the universal perceptual and cognitive biases that have shaped color-term systems across world languages.

Carr et al. (2016) examined the concurrent emergence of categories and linguistic structure. In their study, the continuous meaning space was that of triangles, and the signals were not fixed but rather were an open set that changed as it was transmitted over chains. Participants were trained on a language containing 48 signals denoting as many triangles, and then were asked to name 96 novel random triangles. Half of these triangles, together with their given signals, were used to train the next participant. After 10 generations, convex categories (Gärdenfors 2000) emerged, and languages became simpler and more compressible, as evidenced by the fact that the transmission error decreased over time. Moreover, Carr et al. (2016) extended their paradigm to chains of dyads (**Figure 1**) to reveal that languages that were used for communication as well as transmitted over generations maintained more distinct categories than when they were simply transmitted: They evolved sublexical regularities responsible for a reduction in reproduction error as well as a further increase in structure, or compressibility.

Meaning structure at the level of the sentence also leaves its mark on language. Schouwstra & de Swart (2014) had participants express various scenes using only improvised silent gesture. For scenes involving extensional verbs such as 'throw' or 'swing,' participants produced SOV gestural sequences; for scenes with intensional verbs such as 'dream' or 'think,' where the object is a consequence of the verb, they produced SVO sequences.

In sum, language structure adapts to the structure of meanings through cultural evolutionary processes. Signals for improvised independent meanings match the structure of their referents iconically, whereas sets of unstructured meanings become structured into categories; when meanings have a structure, signals evolve to match it. These processes reduce randomness, and therefore favor simple, regular, compressible communication systems.

4. TRANSMISSION TO NEW LEARNERS

Transmission occurs every time we use language. Children learn language partly by observation, but mostly through use, and individuals' knowledge of language is updated with every episode of use (e.g., Tomasello 2003, Croft & Cruse 2004). Speakers introduce innovations in the language during communicative interactions in context, but the spread and conventionalization of these innovations are guided by processes that operate during transmission, such as cognitive biases and features of the population structure.

4.1. Cognitive Biases

The fact that most structural elements of language remain stable over many generations tells us that social transmission mechanisms such as imitation and learning are mostly faithful (Pagel 2009, Tomasello 2016). The fact that linguistic structure can emerge where there is none, as in cases of emergent sign languages (Meir et al. 2010), tells us that social transmission is biased—some patterns are more likely to be learned and reproduced than others. Any systematic biases on transmission therefore constitute selection pressures that lead to adaptation. These pressures can be modeled as the prior probability of a hypothesis in Bayesian learning (Griffiths & Kalish 2007, Kirby et al. 2014) or can be considered attractors guiding cultural evolution (Claidière et al. 2014a). By having information repeatedly learned and reproduced, experiments can reveal the biases and constraints that operate on the social transmission of language and that, ultimately, shape the distribution of language structures in world languages.

The least-effort bias pervades cognition (Chater & Vitányi 2003), and language is no exception (Zipf 1949). Properties of language that increase its compressibility—that make language easier to perceive, process, or produce—should be favored by this bias. Patterns that are similar to or have associations with existing schemas or representations that we have already learned show increased processing fluidity. Early studies of the effects of transmission include Bartlett's (1932) classic serial reproduction experiments, which investigated the influence of schemas on the reproduction of drawings and stories. His participants were asked, for example, to look at a simple abstract drawing for 10 seconds and then to try to reproduce it from memory as accurately as possible. The drawing produced by a participant was then shown to another participant, in a transmission chain (**Figure 1**). The drawings changed in a nonrandom way: They came to resemble existing schemas, and could transform from, for instance, a meaningless doodle into a cat in a few "generations." Seeking to test whether the effect was due to mere repeated production or to an interaction of the new pattern with the schemas in memory, Tamariz & Kirby (2015) compared transmission chains of either Bartlett's (1932) repeated remembering condition or the copy-from-view condition. In the remembering condition, the drawings became compressible in two ways: As expected, they came to resemble schemas (e.g., letters and numbers), and they became graphically simpler, presumably responding to the limited observation time (10 seconds). In the copy-from-view condition, however, the drawings also changed, but they remained abstract and complex. This finding demonstrates that even very briefly holding a pattern in memory is sufficient for cognitive biases and schemas to leave their mark on it.

These individual cognitive biases, operating at the level of populations over time, are reflected in the patterns of variation observed in world languages (Culbertson et al. 2012, Regier et al. 2015). Culbertson et al. (2012) tested whether learners displayed a cognitive bias in favor of harmonic word-order patterns, which could explain their typological prevalence. They exposed adult learners to artificial languages containing noun phrases of two types: noun plus adjective and noun plus numeral. They manipulated the frequency of different word orders across noun phrases and showed that, indeed, learners regularize the languages by increasing the proportions of the majority word order in both types of noun phrase, in particular when they were harmonic. Smith & Wonnacott (2010) also demonstrated experimentally the elimination by learners of a language feature that is virtually absent from natural languages, namely unpredictable variation. Their languages included sentences formed by a verb; a noun; and, when the noun referred to more than one object, a plural marker. The marker had two forms, 'fip' and 'tay,' one of them three times more frequent than the other but both occurring with all nouns, thus ensuring unpredictability. After being learned and reproduced over five generations in transmission chains, the frequencies tended to be maintained, but the variation became gradually conditioned on lexical item: 'Fip' was used with some nouns and 'tay' with the others. This process created two categories of nouns, akin to gender categories, and a new rule that could be applied regularly, predictably. Using a similar task with dyads instead of transmission chains (**Figure 1**), Smith et al. (2014) and Fehér et al. (2016) found that communicative interaction also led to regularization of unpredictable variation.

The role of children, as opposed to adult learners, as vectors of change has long interested the field of cultural language evolution. In the natural experiment of Nicaraguan Sign Language (the language that spontaneously emerged in a new school for the deaf that brought together deaf children from all over the country), structural traits such as phonemic categories or morphology did not emerge until new cohorts of children joined the signer community, and were never mastered by members of the initial cohorts (Senghas & Coppola 2001). These are the same kinds of structural traits that nonnative learners of a language rarely learn to perfection. This suggests that young, but not adult, learners are biased to expect and produce systematic patterns, and that an influx of new minds is required for the patterns to emerge cumulatively—in other words, for the language structure to adapt to the child learners' biases. Experiments confirm that child learners do inject more regularity and rules into the language than adult learners: Patterns of dots in a grid observed and reproduced in transmission chains of children become easier to reproduce than those produced in chains of adults (Kempe et al. 2015). Children eliminate more irrelevant, unconditioned variation from artificial languages than adults (Hudson Kam & Newport 2005, 2009), and they show a stronger preference than adults for harmonic word-order patterns in noun phrases (Culbertson & Newport 2015). This evidence suggests that cognitive biases for regularity and compressibility operating during learning by adults and, especially, by children could be the causal factors behind the emergence of linguistic structure in cultural language evolution.

The experiments reviewed above reveal the effects of cognitive biases operating in transmission using one of two designs: (*a*) training and testing many participants per condition and (*b*) using transmission chains in different conditions. Reali & Griffiths (2009) compared both designs and showed that transmission chains are able to reveal weak biases that are difficult to quantify in a single generation. In a study of the evolution of frequency distributions, these authors trained participants on a language in which each object was denoted by two words in varying proportions. In the training-and-testing paradigm (equivalent to the first generation of a transmission chain), the proportions of the variant words in the participants' output were similar to those in the input. After 10 generations in the chain, however, unpredictable variation had disappeared in most cases, with a single word left for each meaning.

4.2. Population Size and Composition

The patterns of language transmission in a community of speakers, modulated by population size, connectivity, and composition, have often been invoked as determinants of language structure and as causal factors behind the typological distribution of structural patterns. Languages spoken by few speakers or in circumscribed geographical areas, with little contact with other languages, tend to be morphologically richer and overspecified, whereas those spoken by large, more connected populations with high proportions of nonnative adult learners tend to be simpler and more regular (Wray & Grace 2007; Lupyan & Dale 2010, 2015; Trudgill 2011; Nettle 2012; Bentz & Winter 2013). Cultural language evolution experiments have studied these effects, looking for adaptive responses in the languages. Variability in the input to speakers could be responsible for simplicity in large populations; however, Atkinson et al. (2015) failed to confirm this effect in experiments comparing input spoken by one or multiple voices. Dale & Lupyan (2012) found that American speakers living in areas with a high prevalence of nonnative speakers are relatively more likely to accept regular past tenses (such as 'lighted' or 'bended' for the verbs 'light' and 'bend,' instead of the standard forms 'lit' and 'bent'). This observation suggests that nonnative speakers find irregulars difficult to learn and tend to regularize them in production, thus making the language more regular overall—which, in turn, biases the preferences of native speakers toward regularity.

An intriguing related result is that of Cuskley et al. (2015), who compared the production of past tenses for nonce verbs such as 'wug' by native and nonnative speakers of English, and found that nonnatives' responses contained more irregular verbs. Irregularity, however, was not random but rather modeled on English subrules. For example, a common past-tense response for 'wug' was also 'wug,' which follows the pattern of phonologically similar English verbs 'cut' and 'put.' This result demonstrates that native and nonnative speakers construe and use linguistic rules differently, and confirms that the latter group can introduce nonconventional patterns in a language. One way in which nonstandard patterns can conventionalize is through adaptation of native speakers' linguistic output to match nonnatives' expectations. This is precisely what Little (2011) found experimentally in a study that showed a reduction of morphosyntactic complexity when expert participants, trained in an artificial language, interacted with naïve ones who had little knowledge of the same language, but not when they interacted with other experts.

Taken together, these data indicate that a significant presence of adult, nonnative language learners in a population may favor regularity (or reduce morphosyntactic complexity).

5. CONCLUSION

Language structure is the product of countless instances of communicative use across diverse contexts and many generations of transmission to new learners. The traits that are found in modern languages have been successful in at least three respects. First, because they have arisen in the first place, they are capable of being created by humans. Spontaneous improvisation in the initial experimental rounds of graphical or gestural communication experiments attests our capacity to create and understand novel communicative signals. Second, linguistic traits have spread and conventionalized in speaker communities; therefore, they have outcompeted alternative variants. Iconic signals may be adaptive to designate novel meaning; after repeated interaction, however, simpler, more efficient signals take their place. In other domains of culture, conventionality is not necessary, and many cultural variants can coexist for the same function—for instance, the varied, even incompatible solutions to a given technological problem, such as operating systems or types of engines. By contrast, sharing a signal for a given meaning within a community is essential for successful language function. Third, extant linguistic traits have persisted over generations;

therefore, they can be readily adopted by new learners. Compare computer programming language traits, which are efficient and logical but do not feature in natural languages, with the language-typical morphosyntactic and phonological rules that emerged spontaneously in Nicaraguan Sign Language; or compare the idiosyncratic, independent signals that evolve in dyads in the absence of transmission with the compositional rules emerging in transmission chains (Kirby et al. 2015).

The biases and constraints that explain why languages display the traits they do include human cognition, social dynamics, communicative function, the structure of meanings, and the interactions between these. Cultural language evolution is concerned with explaining the causal pathways that link these biases and constraints with fundamental linguistic traits, such as combinatoriality, compositionality, conventionality, and arbitrariness. This review has examined recent experimental studies of cultural language evolution yielding the following overall findings: Communicative interactions favor initial iconicity and subsequent reduction and therefore compressibility of individual, distinct signals; transmission to new learners favors regularity and therefore compressibility at the level of the whole system; and biases on transmission and communication dictate which types of compressible structure are more likely to emerge.

The first signs that interlocutors improvise in an emergent communication system are iconic or otherwise motivated complex signals (Garrod et al. 2007, Fay et al. 2010, Roberts et al. 2015). Later on, as interlocutors accumulate common ground over repeated interactions, more efficient, simpler, reduced variants of the signals replace the iconic ones. The communicative pressure for disambiguation ensures that signals for different meanings are distinct, keeping simplicity in check (e.g., the introduction of a communicative task in Kirby et al. 2015 preempted the rampant underspecification that had emerged in the languages in Kirby et al. 2008). If the context can be used for disambiguation, the efficiency principle allows homonyms like 'bank' and 'bank' (Silvey et al. 2015, Winters et al. 2015). Communication, then, makes individual signals more compressible, but at the level of the system, it can entrench idiosyncratic, irregular patterns.

Transmission happens when communication extends to new learners who were not involved in the creation of the signs. Learners do not know of the motivation behind the signs, so for them, signs are arbitrary and they adopt them as conventions that ultimately become shared by a community of speakers (Fay et al. 2010). New learners seem to home in on regularities, categories, and rules and, in the absence of counterevidence, overgeneralize them when they need to produce new utterances. As a result of this process, languages become compositional: A finite number of morphemes and rules can yield innumerable utterances (Kirby et al. 2008, 2015). The regularity and compositionality that reduce uncertainty and facilitate production and comprehension also increase the compressibility of languages at the level of the whole system.

Factors that operate during communication (such as the structure of meanings or biases for alignment between interlocutors) and during transmission (including population dynamics and constraints on learning) determine the types of structure that emerge under different circumstances, and ultimately shape the patterns of variation in world languages.

FUTURE ISSUES

1. The field of cultural language evolution could strengthen its ties with evolution in other cultural domains (e.g., Tamariz et al. 2016), and with studies of biological evolution and coevolution.
2. Studies that combine modeling, field studies, and experiments represent the most promising way forward in cultural language evolution.

3. Innovation in experimental design, such as further use of silent gesture (e.g., Motamedi et al. 2016), manipulation of population size and structure, or integration of tasks in more naturalistic games, could expand the scope of the field.
4. An area that is underrepresented but crucial to this field, which could be addressed with novel specially designed experiments, is the differential contribution of children and adults to the emergence of language structure.

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