The Cultural Evolution of Language

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Abstract

Language is one of only a handful of human cultural systems that is both unique to our species, and universal. This chapter will focus on the cultural evolution of language, situating this alongside the phylogenetic and developmental timescales which also feed into the evolution of language. The chapter begins by outlining the relationship between the emergence of human language and the language faculty and the more rapid, ongoing processes of language change, which are often framed as predominantly cultural. In particular, previous work has emphasised how these timescales interact, and how cultural factors in particular shape which aspects of language exhibit broad cross-cultural variation or stability. This is followed by detailed evidence for this relationship from three domains, focusing on the role of cultural evolution in language as observed in natural language (both historical corpora and cross linguistic data), the cultural evolution of language in agent-based models, and finally, experimental studies of the cultural evolution of language. We conclude that the study of the cultural evolution of language forms an important data-rich model for the study of the evolution of cultural systems more generally, while also providing key insights into the specific dynamics of this uniquely human behaviour.

Language sits at the interface of our unparalleled cognitive capacity and the vast symbolic culture that defines us as humans. Language evolution is thus inextricably linked to cultural evolution, providing a rich dataset which can be used to understand both the evolution of language and cultural evolutionary dynamics more generally. We begin this brief overview by situating the cultural evolution of language alongside two other crucial factors in language evolution: language development and biological evolution. We then sketch out the broad evidence for how the cultural evolution of language works in terms of different sources of evidence, from natural language, agent-based modelling, and lab-based experiments.

1 Language as a dynamic system

The links between culture, biology, and learning were made explicit in the study of language evolution by Hurford & Kirby (2002), and these areas have broadly framed both theoretical and empirical work in language evolution. Thus, language evolution has been an early adopter

of a cultural evolutionary framework among the behavioural sciences. This framework characterises the cultural evolution of language as part of a complex dynamic system, interacting with biological evolution and language learning and development.

Here, we briefly outline how the components of this complex system operate on different timescales, with particular focus on their role in the cultural evolution of language.

The physical and cognitive underpinnings of language are ultimately rooted in biological adaptation; in other words, they have evolved on the *phylogenetic* timescale (Lieberman, 2002; Barney, Martelli, Serrurier, & Steele, 2012; Mounier, Noûs, & Balzeau, 2020). Genetic selection that results in population-level adaptation occurs on timescales that typically range from a few hundred generations under conditions of heavy selection (Clarke, Mani, & Wynne, 1985), up to hundreds of millions of years (e.g. Padian & May, 1993). The emergence of language in human phylogeny cannot be studied directly, and reliable comparative reconstruction of historical languages only reaches as far back as roughly six thousand years (Ringe, 1998, though see; Renfrew, 2000).

Language acquisition takes place early in the lifespan of an individual (i.e., on an *ontogenetic timescale*). Typically-developing children exhibit a broadly uniform trajectory of language acquisition, which occurs readily without explicit instruction. This has led to the idea of a ‘critical window’ for language acquisition: a sensitive period early in life during which language is naturally acquired and then becomes fixed (Hurford, 1991). However different features of language differ in the degree to which they fixate in acquisition. The lexicon remains elastic throughout the lifespan, with new words being acquired (and forgotten) well into adulthood and old age. By contrast, a developmental constraint on structure (including word formation, or morphology, and syntactic structure) is evident from cases of child language deprivation. These include not only famed cases of ‘feral’ children such as Genie (Fromkin, Krashen, Curtiss, Rigler, & Rigler, 1974), but also widespread ongoing language deprivation experienced by deaf children (Hall, Levin, & Anderson, 2017). In these cases, full morpho-syntactic development is inhibited by the absence of linguistic input during the formative years, and never fully recovers once this ‘critical window’ has passed sometime in early adolescence (Boudreault & Mayberry, 2006, see ; Cheng, Halgren, & Mayberry, 2018).

Language change, and cultural evolution at large, takes place on a relatively rapid *glossogenetic timescale*. A given instance of language learning requires cultural inheritance from the

ambient population of language users. The learner will, in turn, continue the cultural transmission process by going on to produce utterances that constitute input for future learners. In this way, individual language learning (and, ultimately, the phylogeny of language capabilities) is mediated by an adaptive system of socio-cultural transmission. The most rapid changes like the spread of lexical items can happen on the order of months (e.g. Eisenstein, O'Connor, Smith, & Xing, 2014). Changes that rely more on vertical transmission can occur in one to two generations (e.g. sound changes like the Northern Cities Vowel Shift; McCarthy, 2011), with most structural changes potentially taking much longer - over a thousand years (roughly 35 generations) in the slowest documented cases (e.g. Wallenberg, 2016).

Accumulating evidence suggests that the cultural environment influences biological evolutionary processes in general terms (Boyd & Richerson, 1988; Richerson, 2017), and language is no exception. The coevolution of genes and culture explains human adaptations such as lactase persistence in European populations (Aoki, 1986; Leonardi, Gerbault, Thomas, & Burger, 2012) and a range of morphological and cognitive features associated with self-domestication that were likely especially crucial for the evolution of language (Thomas & Kirby, 2018; see also Raviv and Kirby, this volume). Some models also suggest that the co-evolution of biological and cultural systems can lead to weak cognitive adaptations that underpin the kinds of universals observed in language (Thompson, Kirby, & Smith, 2016; see also, Smith, 2020 for a detailed review).

In the following sections, we summarise insights into the cultural evolution of language from three domains of evidence: natural language data, lab-based experiments, and agent-based models.

2 Natural language

Despite ethical limitations that make the study of language emergence difficult, there are naturally-occurring cases where factors such as learning, ecology, social interaction, and population structure are found to vary. These allow us to understand the cultural evolution of language under conditions of high ecological validity. Here, we examine paradigmatic examples of this from the emergence and evolution of young sign languages (section 2.1), and the distribution of features in modern languages (section 2.2).

2.1 Emergent Sign Languages

The vast majority of deaf children are born to hearing parents (Hall et al., 2017) and, as a consequence of late recognition of their deafness and lack of exposure to visual language, are often not fully exposed to language during the critical window for acquisition. This has inadvertently created conditions that lend themselves to the study of language emergence. When isolated from other deaf individuals, children often establish gestural communication systems innovated together with their family members called ‘homesign’ (Goldin-Meadow, 2012).

The features of homesign can be contrasted with both established and emergent community sign languages, particularly to probe how cultural dynamics change sign systems. The emergence of two new sign languages in particular, Nicaraguan Sign Language (NSL) and Al-Sayyid Bedouin Sign Language (ABSL), are recent enough that the bulk of their cultural transmission histories are known. This allows detailed comparison between the varied conditions of transmission for each generational cohort, and the linguistic features that emerge and change as a result.

NSL was established when education reform in 1970s Nicaragua brought together significant numbers of deaf children for the first time. Before this, the children primarily interacted with hearing family and neighbours through disparate homesign systems, and had no opportunity for interaction with other deaf children (Senghas, 1995; Coppola & Senghas, 2010). After the first cohort in the new school had innovated NSL, subsequent cohorts of deaf children learned NSL in turn. NSL is now a recognised sign language with thousands of signers. Studies of NSL have shown that community transmission plays a crucial role in the emergence of language-like features, particularly relative to isolated home-sign systems. Specifically, cultural processes provide a strong pressure for language-like features related to motion events, as well as stable lexical conventions.

Senghas, Özyürek, and Goldin-Meadow (2010) analysed the encoding of motion events in both homesigners and several cohorts of NSL signers. Well-established signed languages often segment aspects of holistically perceived motion events into separate segments for MANNER (e.g. *rolling*) and PATH (e.g. *down*; (Senghas, Kita, & Özyürek, 2004)). These segments can then be sequenced according to the rules of the language (as in *rolling down* but not **down rolling* in English.) In co-speech gesture, homesign, and early cohorts of NSL, MANNER+PATH are often conflated within a single gesture (e.g., the movement of the hand downward while making a

circular motion with the index finger). By contrast, later cohorts of NSL more often use fully segmented sequences of signs to express MANNER and PATH separately (e.g., making a circular motion with the hand *and then* pointing downward). Thus, community transmission seems to have led to the segmentation of initially holistic signs, resulting in a more segmented, sequential sign-system of the kind often observed elsewhere in more established natural languages (Senghas et al., 2010).

Lexical handshape in nouns and adjectives also differs between homesigners and early NSL cohorts relative to later cohorts (Goldin-Meadow, Brentari, Coppola, Horton, & Senghas, 2015). Greater variability of handshapes is observed in homesigns, which are idiosyncratic enough that an individual may produce different signs for the same referent at different times. This variability is somewhat reduced in the first cohort of NSL, and remains stable in subsequent cohorts (Goldin-Meadow et al., 2015). By comparison, American Sign Language, which is hundreds of years old and has deeper roots in French Sign Language (Shaw & Delaporte, 2011), exhibits consistent and stable use of lexical handshape across individuals. Cultural processes such as horizontal and vertical community transmission exert a strong pressure for a regularised shared lexicon that is absent in the homesign context. In other words, without pressure from a wider cultural community, signals are more likely to be idiosyncratic both within a given signer’s usage across time and across homesigning individuals.

An unrelated sign language, Al-Sayyid Bedouin Sign Language (ABSL), has also emerged during the 20th century among a small community in the Negev Desert in Israel. ABSL is notable particularly because it has key properties unrelated to surrounding languages: its basic word order of Subject-Object-Verb (SOV) is not shared with either the ambient spoken Arabic or with another relatively young sign language in the region, Israeli Sign Language (ISL), both of which are SVO (Sandler, Meir, Padden, & Aronoff, 2005; Sandler et al., 2014). This basic word order was established within a generation, in line with findings from homesign that also suggest stable word order is an early fixture (Goldin-Meadow et al., 2015). In contrast, more complex structural features are stabilised in later generations of signers (Padden, Meir, Aronoff, Sandler, et al., 2010). One such feature is the rule-governed use of space to express grammatical agreement between verbs and their arguments, or between nouns and classifiers. For example, the grammatical rules for using ‘transfer verbs’ like SEND or TELL entail designating participants to different spatial locations and signing the verb-form along a path between them (Meir,

2012). Because this use of space is highly motivated and iconic, this kind of agreement system has been suggested to apply to all sign languages (Aronoff, Meir, & Sandler, 2005). However, analysis of new sign languages shows that this complex agreement is not present in the early stages of emergence in a systematised way. The grammaticalisation of space was also found to be more systematic and solidified in ASL when compared to ISL, which is a much younger language (Meir, Sandler, Padden, Aronoff, et al., 2010), suggesting that cultural processes drive this shift.

2.2 Cross-linguistic similarities and differences

The evidence above suggests that, once a new language has emerged, community transmission pressures play a role in the form, stability, and regularisation of a new language’s grammar and lexicon. This is corroborated by more varied and large-scale natural language data, which details a strong relationship between the complexity of certain rules used in word formation known as *inflectional morphology* and the size and structure of the population of language users. Inflectional morphology is the way in which words are grammatically marked in a language. For example, English generally marks plurality using *-s* (e.g., *dog*, *dogs*). The degree to which information is grammatically marked can vary substantially across languages: while English marks plurality on nouns, other languages have more complex inflectional morphology, also marking gender, case, or other arbitrary classes (e.g., animate vs inanimate).

Cultural factors play a role in this cross-linguistic variation. Languages with larger populations of speakers tend to have simpler inflectional morphology than those of smaller populations (Nettle, 2012). An analysis of morphological features in over 2000 languages showed that larger speaker populations tended to have simpler word forms (Lupyan & Dale, 2010, see also Bentz & Winter, 2013). The mechanisms behind this seem to be related to population size, but their exact nature is still being explored. It could be that small social networks support more complex systems due to a higher concentration of child learners, that smaller networks are more isolated (i.e., lack significant adult-to-adult language contact), that larger populations underwent a process of growth which favoured simplification, or some complex combination of all of these factors (Cuskley, Loreto, & Kirby, 2018). Experimental evidence, reviewed in section 4, plays a key role in distinguishing these mechanisms. Regardless, the early conditions of language emergence likely involved close-knit networks of speakers with relatively small group sizes which fostered

the emergence of more complex language systems. Complex linguistic morphology may therefore constitute a ‘default’ state in the evolutionary history of a language, with simplified inflectional morphology developing as a result of greater cultural transmission among large populations with a greater concentration of adult learners (Wray & Grace, 2007).

Cultural transmission under different conditions can lead to shared properties across disparate languages, but also plays a central role in language diversity. One principle task of a language is to represent meaning categories that exist in the world, yet languages sometimes carve up the meaning space in quite different ways. For example, the spatial preposition *on* in English encompasses varied topological relations such as vertical surfaces (e.g., *a magnet on a fridge*) and interlocking surfaces (e.g., *a cap on a pen*), whereas in Korean it is restricted only to horizontal surfaces (e.g., *a cup on a table*) (Bowerman & Choi, 2003). A recent large scale analysis of words in 41 languages identified the domains of meaning that are most given to this kind of divergence (Thompson, Roberts, & Lupyan, 2020). Terms for very highly structured and stable meaning domains like kinship, number and quantity showed high overlap in the boundaries used across languages. Many other common terms for categories, artefacts, and common actions, however, were much less aligned in their contexts of use. Where overlap was highest in these domains, it was the result of a shared geography and linguistic lineage. In other words, the way that speakers categorise meaning in language seems to be strongly constrained by shared cultural history.

Language for fundamental perceptual domains such as olfaction can also show considerable diversity (Majid, 2020). While English has a very limited lexicon for odors and speakers talk about smell infrequently, other languages have large inventories of smell terminology, sometimes even appearing in the grammar. This difference in olfactory language reflects a concomitant difference in the role of olfaction in cultural practice and the cultural niche of the language. Majid and Kruspe (2018) found that speakers of two related Austroasiatic languages, Semelai and Semaq Beri, exhibit different performance odour naming, despite being spoken in similar ecological environments (spoken in the Malay peninsula): Semaq Beri speakers have a larger odour vocabulary which they use more consistently than Semelai speakers. Majid and Kruspe (2018) suggest this is due primarily to differences in subsistence, with the Semaq Beri out-performing the Semelai due in large part to their hunter-gather culture. Accompanying experimental work also indicates that accuracy of smell perception differs along these cultural and linguistic lines

(Majid, 2020).

Overall, the evidence from natural language suggests a complex interplay of individual learning pressures, biases in human perception, and the cultural system of language. To test the causal factors that underpin these phenomena, researchers must turn to other methods of investigation.

3 Agent-based models

Agent-based modelling provides an opportunity to examine complex, population level phenomena in a controlled way, allowing us to test specific hypotheses generated by evidence in natural language, as well as generating hypotheses that can be tested in experimental settings (section 4). These models can investigate the cultural evolution of language under many different kinds of conditions. Here, we consider two general approaches to agent-based modelling in the cultural evolution of language: those that focus on individual learning and transmission, and those that focus on linguistic outcomes over larger populations of agents.

3.1 Iterated learning

Early efforts in linguistics that focused on individual learning were generally unconcerned with cultural processes, instead focusing on properties of the individual learner. For example, Rumelhart and McClelland’s influential connectionist model investigated mechanisms for learning the past tense in English, and as such was centrally concerned with the individual learner’s internal architecture (see McClelland & Patterson, 2002 for an overview).

However, the early 2000s saw researchers begin to investigate how cultural processes might contribute to structure in language (see Kirby, Griffiths, and Smith (2014) for an overview). In other words, while early models focused on how learners internalised existing structure in language input, later approaches began to probe how cultural transmission contributed to the *emergence* of language structure in the first place. Models in this vein generally involve chains of individual agents who learn and produce a series of form-meaning mappings. Importantly, a modelling approach allows for hundreds or thousands of chains with similar starting conditions, giving a concrete picture of the distribution of possible linguistic outcomes, and thus the robustness of results.

Three crucial features characterise these models: (i) agent N is tasked with producing items they were not trained on during learning (i.e., there is a bottleneck in learning), and (ii) their productions become the learning input for agent $N + 1$, and (iii) this process is iterated: the productions of agent $N + 1$ become the input for agent $N + 2$, and so on. Exactly how agents learn and produce in this context can vary, from relatively simple production strategies and confined vocabularies (Kirby & Hurford, 2002) to more complex Bayesian agents (Real & Griffiths, 2009) or learners that implement more construction-based chunking strategies (Isbilen & Christiansen, 2020).

The central result of these iterated learning models is that *the process of cultural transmission can amplify relatively small learner biases*, resulting in the rapid emergence of structure. In other words, learners need not necessarily have strong, domain specific biases related to language structure in order for language systems to display emergent structure (Ferdinand, Kirby, & Smith, 2019). These models show that the *combination* of weak biases and cultural transmission is sufficient to produce structured language systems. While debate remains as to the domain specificity and strength of biases related to language learning (especially in an evolutionary context Pleyer and Hartmann (2019)), these models show the potential power of cultural transmission. While many of these models focus mainly on chains of individual learners, they have also been extended to look at populations (Smith, 2009).

3.2 The Naming Game

In parallel with iterated learning, artificial intelligence research gave rise to another agent-based modelling paradigm. This approach focused less on individual biases and more on processes of interaction between agents, scaling up to cultural evolutionary dynamics in language at the population level. This began with the ‘talking heads’ experiment (Steels, 2015), which focused on two embodied agents interacting iteratively, situated in an environment with slightly different visual perspectives. Here, the original focus was not on structure, but convention formation: how could situated agents develop a shared vocabulary? The original talking heads experiment shared many features with early versions of the iterated learning model, although there were important differences. While the talking heads experiment focused on conventions, embodiment and repeated paired interactions, the iterated learning model focused on structure, a learning bottleneck, and transmission. However, both focused fundamentally on paired interactions and

the emergence of language.

The talking heads experiment eventually extended into a less-embodied version called the naming game (Baronchelli, 2016), where larger populations of agents interacted over random networks and multiple related meanings to form a shared vocabulary. In its simplest version, agents stored all encountered strings until they interacted with an agent that shared one string in common, at which point the common string was kept by both agents while others were discarded. More complex versions have investigated different memory constraints (Fu, Cai, & Zhang, 2017), or more complex interaction networks (Baronchelli, Dall'Asta, Barrat, & Loreto, 2007), but the general dynamics remain the same: through repeated interaction, agents reliably converge on shared conventions at a rate that scales with the overall population size (Baronchelli, 2016). This approach has also been extended to investigate the dynamics and emergence of language structure in populations of interacting agents (Cuskley et al., 2017, 2018). Overall, the naming game underscores results from the iterated learning model: small individual biases are amplified by cultural processes - in this case, repeated interaction instead of transmission.

Iterated learning and the naming game have been particularly influential in the study of language evolution, particularly in highlighting the role of cultural processes in the emergence of key features of language. Spike, Stadler, Kirby, and Smith (2017) made a detailed comparison of different models of learned signalling and identified information loss as a key factor in the emergence of conventions (through a learning bottleneck in iterated models and memory limitations in the naming game). However, agent-based modelling is a vast toolkit for investigation into cultural phenomena, and many different approaches have shed light on language evolution.

3.3 Other modelling approaches

Other models have investigated various parameters of populations and transmission dynamics. Reali, Chater, and Christiansen (2018) used agent-based modelling to shed light on the possible mechanism by which large population sizes give rise to languages with simpler inflectional morphology. In this investigation, linguistic items were either *easy* to learn (learnable from fewer exposures), or *difficult* (learnable from many exposures). Only small populations where all agents interacted with each other were able to provide the number of exposures needed for difficult conventions to be preserved and proliferate in the language. As such, the *learnability* of a convention can determine whether it survives in, and can be diffused through, a large pop-

ulation. Put differently, variation in the properties of cultural items, rather than variation in the abilities of learners, can give rise to structural changes in the language at large in response to population size.

The ability to test population parameters under different conditions can also shed light on dynamics of gene-culture coevolution. Sign languages are an area where the genetic and cultural interplay is of particular interest, since deafness in a population may be genetically inherited, as is the situation accompanying ABSL and other village sign languages (Padden et al., 2010). While congenital deafness can skip generations if it is genetically recessive, if a sign language is to persist, it needs to be transmitted regardless of whether the deaf phenotype occurs consistently across generations. In order to persist (as sign languages such as ASL have for over 200 years), varied cultural processes must play a crucial role. An early model of the genetic and cultural parameters of sign language transmission by Aoki & Feldman (1991, 1994) found that the persistence of sign language through vertical transmission modes was more likely under certain conditions: a population where many hearing persons acquired sign language; a high frequency of recessive alleles for deafness in the population, or; a high frequency of deaf persons marrying other deaf persons. Later models incorporated parameters observed in communities like the Al-Sayyid Bedouin, where deaf individuals are socially integrated, and rates of deaf-hearing marriage and fluent hearing signers are exceptionally high. By modelling these real-world parameters, Gialluisi, Dediu, Francks, and Fisher (2013) showed that deaf-hearing marriage patterns are able to help sign languages persist. Most recently, the role of hearing signers and various modes of cultural transmission (such as from grandparents and unrelated members of older generations, as well as horizontal transmission patterns) have been shown to bolster the persistence of sign language in a population (Mudd, de Vos, & De Boer, 2020).

4 Lab-based experiments

Over the last decade and a half, experimental paradigms in the cultural evolution of language have shed light on the causal links between cultural evolutionary factors and the fundamental design features of language (see Tamariz, 2017, for a comprehensive and detailed review). These typically involve communication games that require participants to either produce novel conventions or learn pre-specified artificial languages.

In artificial language learning (ALL), ‘languages’ are generated using simple, usually un-

structured, form-meaning mappings. To study the cultural evolution of language, ALL can be integrated with iterated learning. This was inspired in large part by the same approach in agent-based modelling (see section 3), however, it reaches back to transmission chain studies done in the early 20th century (see Cuskley, 2019, for further detail). Like iterated agent-based models before them, this process involves three crucial features: (i) participant N is trained on random (but usually pre-specified) form-meaning mappings, and then tasked with producing items they were not trained on during learning (i.e., there is a bottleneck in learning), (ii) their productions become the learning input for participant $N + 1$, and (iii) this process is iterated: the productions of participant $N + 1$ become the input for participant $N + 2$, and so on. The precision and control afforded by the use of artificial languages in experimental conditions allow investigators to measure how the features of such languages emerge in response to a variety of factors, such as learning constraints, transmission dynamics, and parameters of the task and context.

The broad picture that emerges from experimental evidence echoes findings from both natural language and modelling: cultural transmission of language simultaneously provides a strong pressure for learnable, expressive structure, and for the emergence of shared conventions. Repeated learning and use regularises the language structure in multiple ways, most notably in response to competing pressures for learnability and expressivity. While learnability pressures come from the process of acquisition in an individual, expressivity only emerges in cultural context. The particular demands of communication and interaction (such as the meanings to be communicated, the disambiguating context, and the shared history of interlocutors) shape how conventions become symbolic and are mapped structurally onto categories of meaning. Finally, the structure and dynamics of the population itself also influence the way these transmission processes unfold, affecting how language forms are diffused, learned, and shaped.

4.1 Cultural transmission and language structure

A key early finding of this paradigm is that compositional structure - the property of language whereby the meaning of a string is a function of the meaning of its parts and how they're put together - emerges through transmission. More specifically, this structural property emerges from the repeated application of competing pressures for *learnability* and *expressivity* (see also Kirby, Tamariz, Cornish, & Smith, 2015; Tamariz & Kirby, 2016 Kirby, Cornish, & Smith, 2008). In

order to survive and be transmitted to the next generation, languages must be learnable by individuals who are exposed to only a subset of possible utterances (see Chater & Vitányi, 2003; Kemp & Regier, 2012; Ferrer-i Cancho et al., 2013). We might imagine, for example, that the most easily-learned (but not at all useful) language would consist of a single short word to convey all possible meanings. However, a counteracting pressure for *expressivity* means that language must meet the functional requirements of discriminating between different meanings; we could imagine that a maximally expressive (but necessarily unlearnable) language designates a unique word to every possible unit of meaning, such that the inventory is arbitrarily large and cannot be captured by generalised rules. Natural language emerges from the trade-off of these two competing extremes, resulting in a system of structured, learnable units with meaningful compositional structure and generalised rules. Regularised structure improves the transmissibility of the whole system; since linguistic items must either be learnable from direct exposure or inferable from the items that have been learned, generaliseable rules allow items that have not been learned by exposure to stay in use and be transmitted nonetheless. The cultural evolution of language through repeated learning and use thereby provides a key mechanism for the emergence of adaptive linguistic design (Kirby et al., 2015).

Subsequent experiments have shown that these competing pressures for learnability and utility give rise to a range of universal properties of language through the mechanism of cumulative cultural transmission. One such universal is duality of patterning, whereby discrete units are recombined into a potentially infinite set of sequences. In an experimental task using continuous whistles, the emergence of discrete whistle motifs that could be recombined emerged through the process of cumulative cultural transmission (Verhoef, 2012). Zipf’s law of abbreviation means that more frequent words are likely to be shorter, whereas infrequently used words are longer - a property considered to apply to all natural languages. In a dyadic communication experiment, this inverse relationship between word length and frequency only emerged under conditions where the communicative pressure for expressivity *and* the pressure to compress for efficiency were both at play during transmission (Kanwal, Smith, Culbertson, & Kirby, 2017).

Cultural evolutionary processes have also been shown to regularise grammatical features of artificial sign languages. Using chains of participants trained on an artificial sign language, the consistent and systematic use of space to distinguish between sentence arguments was shown to emerge over transmission (Motamedi, Schouwstra, Culbertson, Smith, & Kirby, 2017). The

differing strategies employed by different chains (such as handshape, body orientation, and location indexing) all paralleled strategies used in the grammar of natural sign languages, reflecting the highly motivated affordances of the manual modality. Across all of these strategies, the earliest iterations showed no clear systematised convention for distinguishing arguments; by the last iterations, these had regularised into a systematic set of features (Motamedi et al., 2017). These findings mirror the natural language evidence (see section 2.1), which shows that spatial agreement is late to emerge in the transmission history of new sign languages.

4.2 Cultural transmission and symbolic convention

A pioneering study by Garrod et al (2007) used a pictorial-style drawing task to explore how interacting pairs establish referential conventions. The pictorial task involves multiple rounds wherein a Director depicts a meaning by drawing a picture, while a Matcher guesses the intended referent of the picture from a finite set. Drawings in initial rounds were detailed, iconic, and transparent: the drawings fundamentally resembled the referents (e.g., a detailed drawing of a screen with a mouse for ‘computer’). However, over multiple rounds, the drawings became both less transparent and more simplified: naive third participants were unable to recover the meaning of symbols that resulted from games they had not been involved in (Garrod et al., 2007).

This communication and feedback between Directors and Matchers is crucial: in conditions without this, representations instead became increasingly detailed and complex. This finding illustrates that if interaction allows a complex convention to take hold, subsequent pressures for ease of reproducibility compress forms such that they simplify, and this loss in complexity entails a loss in resemblance or iconicity. Highly iconic beginnings that are heavily bound to the particular context and history of interaction can become abstracted and formalised through interactive pressures, which may mirror processes at play in the emergence of language (Cuskey & Kirby, 2013).

The evolution of graphical conventions also exhibits selection dynamics. In a Pictorial-style task that explored the diffusion of graphical symbols in small groups, Tamariz, Ellison, Barr, and Fay (2014) found that while players favoured the symbols they had used before, they sometimes adopted others that were considered a better ‘fit’ for the intended meaning. In other words, some graphical symbols are fitter than others, and cultural context can determine fitness,

playing a significant role in the evolution of symbol systems (see also section 4.3).

The way languages encode meaning is also affected by the cumulative amplification of individual learning biases enabled by cultural transmission. In an iterated artificial language game in which some dimensions of meaning were more pertinent than others for the communicative task, the resultant categories of meaning were determined by the meaning dimensions most salient given the task (Silvey, Kirby, & Smith, 2015). Importantly, in the earliest generations of participants the effect of salience on encoded meaning was very weak; only in later generations was systematic encoding of salient meaning dimensions observed (Silvey et al., 2015). While the vast majority of work in this area uses abstract meaning spaces which already have a clear, pre-specified structure, Carr, Smith, Cornish, and Kirby (2017) tasked participants with learning mappings in an open-ended continuous meaning space (triangles whose vertices could have any coordinates). They found that participants impose shared structure on the meaning space in the process of creating shared, structured mappings in an iterated task. Echoing findings from natural language and agent based models, these results indicate that language does not replicate fixed meaning categories in the world, but carves up the world according to malleable learner biases and communicative need. Thus, meaning spaces in language and cognition arise in part from a complex cultural process of repeated learning and use in context.

4.3 Language structure and population structure in the lab

Transmission through a population is a central mechanism of cultural evolutionary processes, including language evolution. Evidence shows that the connectivity and interaction of a population is a key factor in shaping communication systems. Unlike the use of natural language data, experimental use of ‘microsocieties’ allows specific features of the population to be causally tested in isolation from each other. In an artificial language learning experiment with repeated interactions in either small (four participant) or large (eight participant) groups that were fully connected, Raviv, Meyer, and Lev-Ari (2019b) had participants create non-word labels for various shapes that varied systematically in terms of their form, texture, and movement (i.e., there was a highly structured meaning space). This work provides a systematic test of the mechanisms proposed for earlier findings in natural language regarding population size and language structure (Lupyan & Dale, 2010). Raviv et al. (2019b) found that repeated interaction between participants in larger groups led to simpler, more systematic language structure, while smaller

groups had more idiosyncratic systems that were less predictable but nonetheless communicatively effective.

Later work in this vein showed that the internal network structure of these kinds of microsocieties (e.g., whether they were fully connected or had small-world network properties) had little effect on the regularisation of artificial languages (Raviv, Meyer, & Lev-Ari, 2020). This result is underscored by results from graphical communication tasks: larger communities give rise to more systematic and useable graphical representation systems (Fay & Ellison, 2013), and signs that are more decodable by naive onlookers (Fay, Garrod, & Roberts, 2008).

The importance of intragenerational social collaboration in the development of language is also demonstrated by experimental microsocieties. Interaction between language users alone can give rise to compositional structure, without intergenerational transmission (Raviv, Meyer, & Lev-Ari, 2019a). In addition, community-level alignment on efficient signs can be achieved by pair-wise interactions of members within a highly connected microsociety, rather than by isolated pairs or vertical transmission (Fay, Garrod, Roberts, & Swoboda, 2010). Crucially, this emerged even though participants had no knowledge of their interactive partner’s group membership in the task. Together these findings highlight the centrality of horizontal cultural processes like social collaboration in the evolution of communication systems.

5 Conclusion

The study of the cultural evolution of language forms an important data-rich model for the study of the evolution of cultural systems more generally, while also providing key insights into the specific dynamics of this uniquely human behaviour.

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