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The emergence of systematicity: How environmental and communicative factors shape a novel communication system

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ABSTRACT

Where does linguistic structure come from? We suggest that systematicity in language evolves adaptively in response to environmental and contextual affordances associated with the practice of communication itself. In two experiments, we used a silent gesture referential game paradigm to investigate environmental and social factors promoting the propagation of systematicity in a novel communication system. We found that structure in the emerging communication systems evolve contingent on structural properties of the environment. More specifically, interlocutors spontaneously relied on structural features of the referent stimuli they communicated about to motivate systematic aspects of the evolving communication system even when idiosyncratic iconic strategies were equally afforded. Furthermore, we found systematicity to be promoted by the nature of the referent environment. When the referent environment was open and unstable, analytic systematic strategies were more likely to emerge compared to stimulus environments with a closed set of referents. Lastly, we found that displacement of communication promoted systematicity. That is, when interlocutors had to communicate about items not immediately present in the moment of communication, they were more likely to evolve systematic solutions, supposedly due to working memory advantages. Together, our findings provide experimental evidence for the idea that linguistic structure evolves adaptively from contextually situated language use.

1. Introduction

Systematicity permeates language at all levels. Most languages, for instance, show consistent constituent orders (e.g. Subject-Object-Verb vs. Subject-Verb-Object), compositionality (e.g. systematic marking of tense, gender, case, number etc.), semantic roles or even systematic sound-meaning mappings as in phonaestheme clusters such as *glimmer*, *glare*, *glisten* (Bergen, 2004; Monaghan, Shillcock, Christiansen, & Kirby, 2014). Systematicity thus refers to statistical relationships between forms that relate in their meanings, ultimately constituting 'categories' on the form side. But where does systematicity come from? What are the cognitive and communicative factors that promote the persuasive propagation of systematicity across almost all aspects of linguistic structure?

Controversies exist in the language sciences concerning the foundations of linguistic structure. Some theories favour biological explanations grounding linguistic structure in innate genetic code (Chomsky, 1986; Hauser, Chomsky, & Fitch, 2002; Pinker, 1994). Another prevalent suggestion is that systematicity emerges in response to internal, cognitive biases that get amplified through transmission and learning in processes of cultural evolution (Brighton, 2002; Christiansen & Chater, 2008; Kirby, Cornish, & Smith, 2008; Kirby, Griffiths, & Smith, 2014; Kirby, Tamariz, Cornish, & Smith, 2015; Smith, Brighton, & Kirby, 2003). Using the 'iterated learning paradigm', Kirby and colleagues have investigated how sign systems become increasingly ordered, compressible and easier to learn and process, as they are transmitted from one generation to another, due to subtle unintended distortions as signs pass through cognitive bottlenecks and biases of language learners (Kirby et al., 2008). However, it is unclear where this human propensity for systematicity comes from and how specific features are selected and become expressed in systematic categories.

In this paper, we explore the circumstances under which systematic strategies evolve in communicative interaction when referents can also potentially be disambiguated using idiosyncratic, holistic signs. By "circumstances", we mean factors that pertain to aspects of the referent environment and communicative situation. The idea that linguistic structure is promoted by a number of external, contextual factors has

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recently been coined the *Linguistic Niche Hypothesis* (Lupyan & Dale, 2010). In particular, we suggest that systematicity in language emerges adaptively in response to environmental and social factors associated with the situated interactive practice of communication itself (rather than individual learning, Tylén, Fusaroli, Bundgaard, & Østergaard, 2013). That is, linguistic structure is motivated by, and evolves contingent on, structural properties of the physical and social environment. Recent studies provide cross-sectional/correlational evidence for the idea that linguistic structure is contingent on environmental factors, thus suggesting that languages evolve adaptively to meet ecological affordances. Examples include climate influencing the lexicon (Lindsey & Brown, 2002; Regier, Carstensen, & Kemp, 2016) or sound systems (Everett, Blasi, & Roberts, 2015, 2016), subtle genetic or anatomic biases guiding variation (Dediu, Janssen, & Moisik, 2017; Dediu & Ladd, 2007), as well as social factors such as number of speakers that has been found to affect morphological complexity (Dale & Lupyan, 2010; Lupyan & Dale, 2016).

In this study, we take an experimental approach to address the question whether there are specific environmental circumstances under which systematic categories and signs are more adaptive and thus more likely to evolve in competition with non-systematic strategies that might also provide viable solutions. We first define what distinguishes systematic signs from idiosyncratic signs and then individuate three complementary environmental factors hypothesized to promote systematicity in an evolving communication system: i) inherent structure of the referent scenes, ii) instability/openness of the referent environment, and iii) displacement of the communicative environment from the referential scene

1.1. Functional pressures for systematicity, iconicity, and arbitrariness

Systematicity contrasts with other referential principles such as iconicity and arbitrariness that describe the relation between single signs and their meanings. De Saussure (1959) famously argued the defining trait of language to be 'arbitrariness of the linguistic sign' and thus inaugurated a widely endorsed linguistic tradition relegating non-arbitrariness to the role of a rare and peculiar phenomenon to be mostly ignored. However, recent work has highlighted subtle motivations underlying linguistic structure (Kirby, Dowman, & Griffiths, 2007; Lupyan & Dale, 2016). Examples include studies of ideophones, sound symbolism and systematicity (Dingemanse, 2012; Dingemanse, Blasi, Lupyan, Christiansen, & Monaghan, 2015; Monaghan, Mattock, & Walker, 2012). A general tendency in this literature has been to subsume iconicity and systematicity under 'non-arbitrary forms' as opposed to 'arbitrary forms' (e.g. Monaghan et al., 2014). However, iconicity and systematicity could in fact be argued to be the expression of diverse adaptive pressures (Dingemanse et al., 2015).

Iconic signs are motivated in that there is a resemblance between their form and meaning (Peirce, 1931). Iconicity has thus been suggested to play a prominent role in the grounding of communication systems as mappings between form and embodied experience on both phylo- and ontogenetic time scales (Fay, Ellison, & Garrod, 2014; Harnad, 1990; Perniss, Thompson, & Vigliocco, 2010). In language acquisition, iconic sound-referent mappings seem to facilitate early word-learning (Imai & Kita, 2014; Imai, Kita, Nagumo, & Okada, 2008; Perlman, Fusaroli, Fein, & Naigles, 2017; Perry, Perlman, & Lupyan, 2015) as well as novel word learning in adults (Bergen, 2004; Lockwood, Dingemanse, & Hagoort, 2016). In addition, experimental lab studies of emergent communication systems indicate iconicity as one of the main strategies employed whenever signs are grounded from scratch in interaction (Fay et al., 2014; Perlman, Dale, & Lupyan, 2015; Perlman & Lupyan, 2018). For example, in studies where participants invent new communication systems using a graphical medium, iconicity serves as a starting point for bootstrapping communication, after which signs become gradually simpler and more symbolic (Caldwell & Smith, 2012; Garrod, Fay, Lee, Oberlander, & MacLeod, 2007).

However, if iconicity provides such efficient means to ground a communication system, why do natural languages only display rather subtle aspects of iconicity? And why do we generally observe iconicity to decay over time in favour of more systematic and arbitrary mappings (Garrod et al., 2007; Little, Perlman, & Eryilmaz, 2017)? As evidenced in, for instance, emerging sign languages (Senghas, Kita, & Özyürek, 2004; Vos & Pfau, 2015) home signs (Haviland, 2013; Mylander & Goldin-Meadow, 1991), and semiotic experimental studies (Galantucci, Garrod, & Roberts, 2012; Tamariz, 2017), sign systems often set off as a set of individual, idiosyncratic mappings to referents (Deacon, 1998). Over time, the sign repertoire evolves and regularities among and relations between individual signs emerge, which eventually give the repertoire properties of *a system*. As relations among a set of signs stabilize, they provide an alternative means to ground new signs: the meaning of a sign is thus not only constituted by the concrete mapping to a referent, but also by its more abstract relations to other signs in the system. Resulting statistical regularities have been suggested to shift the mnemonic strategy of learners to rely increasingly on the relations among signs (Deacon, 1998) and allow them to quickly categorise newly encountered signs, generalize them and incorporate them into the wider system. Indeed, studies have shown that language-specific statistical differences in word forms (e.g., verb vs. noun morphology) serve as cues that assist category learning (Cassidy & Kelly, 1991; see Dingemanse et al., 2015 for a review; Monaghan, Chater, & Christiansen, 2005; Monaghan, Christiansen, & Chater, 2007). Consequently, signs gradually lose their motivated connection to referents and become increasingly systematic as they come to increasingly depend on their interrelations internally within the communication system.

Thus, while iconicity and systematicity have often been treated as an expression of the same basic pressure of 'motivation' compared to arbitrariness (e.g. Monaghan et al., 2014), they might be better conceived as orthogonal phenomena related to different adaptive pressures (see also Dingemanse et al., 2015; Nielsen, 2016).

1.2. Outline of the study

The current study was designed to address the circumstances under which systematicity evolves in a novel sign system even if idiosyncratic signs are equally afforded. In many situations both strategies would apply: For instance, if one were to point out a specific person among a crowd of people, one could rely on a single discriminating idiosyncratic trait such as "the person with the funny-looking beard" or "the individual with shiny red shoes": However, one could also disambiguate the referent by pointing to a specific *combination* of more general traits, like gender and job category, as in the example "the female doctor" (as opposed to male doctors). When grounding a novel communication system, what are the conditions that promote the latter systematic (analytic) strategy in contrast to a simple idiosynchratic (iconic, holistic) strategy? That is, when is systematicity more adaptive than encoding single features of referents in one-to-one form-meaning mappings?

Building on the general assumptions of the Linguistic Niche Hypothesis suggesting that systematicity evolves adaptively in response to particular ecological and social affordances, this study sets out to test three complementary hypotheses:

(1) Systematicity in communication systems is motivated by regularities in the environment. When new signs evolve under pressure for social coordination and communication, salient relations among referents provide a semiotic resource, motivating systematic structure of the emergent sign forms (Christensen, Fusaroli, & Tylén, 2016; Lupyan & Dale, 2016; Tinits, Nölle, & Hartmann, 2017; Tylén et al., 2013; Winters, Kirby, & Smith, 2015). Following such predictions, people will be more inclined to selectively systematize those dimensions of their communication system that also appear