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Emergence of systematic iconicity: transmission, interaction and analogy

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Abstract

Languages combine arbitrary and iconic signals. How do iconic signals emerge and when do they persist? We present an experimental study of the role of iconicity in the emergence of structure in an artificial language. Using an iterated communication game in which we control the signalling medium as well as the meaning space, we study the evolution of communicative signals in transmission chains. This sheds light on how affordances of the communication medium shape and constrain the mappability and transmissibility of form-meaning pairs. We find that iconic signals can form the building blocks for wider compositional patterns.

Keywords: iconicity, language evolution, iterated learning, social coordination, cultural transmission, analogy.

Introduction

In the emergence of communicative signals, links are established between linguistic form and meaning. These links are usually thought to be arbitrary for the majority of meanings (De Saussure, 1916; Hockett, 1960). However, more recently the importance of non-arbitrary links in linguistic forms (Perniss, Thompson & Vigliocco, 2010) and language evolution (Ramachandran & Hubbard, 2001) has been getting more attention. Iconicity, in which there is a perceived resemblance between form and meaning, seems to play a larger role than was originally assumed (Perniss, Thompson & Vigliocco, 2010), especially when looking not only at spoken Indo-European languages. Sign languages, perhaps more obviously than spoken languages, are rich in iconic forms (Mandel, 1977; Taub, 2001; Meir, Padden, Aronoff & Sandler, 2013) and there are also many spoken languages that have large inventories of sound-symbolic words, known as mimetics (Kita, 1997), expressives (Diffloth, 1972) or, cross-linguistically, ideophones (Dingemans, 2012).

When does iconicity emerge and persist?

We investigate experimentally what factors influence the emergence of iconic forms in language and when these forms are expected to persist. We focus on the mappability of aspects of meaning to aspects of the signalling medium,

and on the transmissibility of iconic forms on the basis of transparency, structure and learnability.

Mappability One factor that is relevant for the emergence of iconicity is how easy it is to map certain forms with certain meanings (Dingemans, 2013). Not all meanings lend themselves well to forming iconic mappings in each communication medium. Spatial relations for instance are generally easier to map onto manual signals, while meanings related to sounds are easier to represent iconically with spoken signals. The affordances of the signalling medium influence the mappability of form-meaning pairs and this influences the iconic strategies that may be recruited in the emergence of languages.

Transparency Iconic signals can be seen as more transparent than arbitrary signals because their form reveals something about their meaning. They may therefore be easy to interpret and remember, and it has been proposed that such forms may have played an important role in the bootstrapping and grounding of early linguistic forms in both development (Maurer et al. 2006, Imai et al. 2008) and language evolution (Ramachandran & Hubbard, 2001). However, there is also evidence suggesting that forms with some degree of iconicity are not always easier to learn than non-iconic signals (Ortega & Morgan, 2010) and that arbitrariness may provide a learning advantage too (Gasser, 2004; Monaghan & Christiansen, 2006).

Many different strategies can be used to represent a meaning iconically (Meir et al., 2013), and it is not in all cases trivial to predict which strategy or type would be the most preferred. Moreover, interpretation of iconicity highly relies on shared expectations and experiences outside of linguistic regularities, which may not be shared by all languages users and be less accessible to very young children acquiring their language (Tolar, Lederberg, Sonali & Tomasello, 2008). Thus, iconicity is not by itself a guarantee for learnability and transmissibility.

Systematic iconicity Iconicity is rarely monolithic (Meir et al. 2013), and there are many different types. Simple one to one resemblances of words to meanings (familiar from

onomatopoeia like *boom* and *moo*) are relatively limited in natural languages. More prevalent uses of iconicity involve predictable and more or less productive patterns, where iconicity is a shared property among groups of signals, systematically related or productively applicable to word classes (Mandel, 1977; Meir et al., 2013; Padden, Meir, Hwang, Lepic & Seegers & Sampson, 2013; Padden, Hwang, Lepic & Seegers, 2014). An example of this in sign languages is lexical patterning (Padden et al., 2013; 2014), where word categories can be identified by a sign reflecting for instance what a tool looks like (noun) versus showing how it is used (verb), which are both iconic forms. In spoken language ideophones, related word forms often depict related meanings, as in Japanese *goro* 'a heavy object rolling', *koro* 'light object rolling' and *korokoro* 'many light objects rolling' (Vigliocco & Kita, 2006). We might expect patterns of this kind to be more transmissible, given their predictable and productive properties, which may in turn influence their persistence.

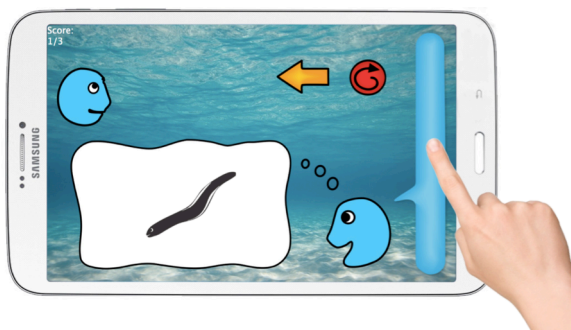


Figure 1: The interface of the experiment, showing a meaning to be communicated and the signal bar.

Pattern emergence Cultural transmission of linguistic structures can be studied experimentally. For instance, languages tend to become more regular and systematic over time when they are transmitted from generation to generation (Hare & Elman, 1995; Kirby, 2001; Kirby, Cornish & Smith, 2008; Kirby, Griffiths & Smith, 2014; Reali & Griffiths, 2009). Cultural transmission experiments that focused specifically on the role of iconicity and arbitrariness reveal that iconic forms sometimes become more abstract and arbitrary when they are transmitted and become part of emerging sub-lexical patterns. Santiago, Tamariz, Vigliocco & Vinson (2014) observed effects of biases for using iconic forms, but only when participants interacted communicatively. A transition from more iconicity to more arbitrariness was also demonstrated in social coordination experiments where novel communication systems emerge through interaction (Garrod, Fay, Lee, Oberlander, & MacLeod, 2007; Theisen, Oberlander & Kirby, 2010). Earlier studies did not focus on systematic iconicity, and did not systematically control both the signalling medium and the meaning space in the same experiment.

Here we combine a social coordination task with a vertical transmission paradigm to study the emergence and

evolution of communicative signals in artificial languages. We investigate both the initial emergence of iconic forms for mappable and less mappable meanings, and the systematic reuse of iconic strategies. Different from prior work (e.g. Garrod et al. 2010), we control both the set of *meanings* and the signalling *medium*, making it possible to study how signals differ in communicative success, learnability, and stability over time.

Methods

The experiment consists of dyadic interactions in which pairs of participants played guessing games together. They could only communicate using sound signals, resulting in artificial whistle-like languages, as in Verhoef (2012). At the end of a trial, a pair's set of signals formed a new language, following the experimental design of Tamariz, Cornish, Roberts & Kirby (2012). The next pair was trained on that language before a new trial started. This created several parallel chains of transmission in which the artificial languages developed over time.

Signals

Participants communicated using a vertical bar on a touch screen, which could be used to create signals that vary in pitch over time. The pitch could be manipulated by sliding the finger up and down, where the top of the bar produced higher pitch and the bottom lower. Signals could be discontinuous (e.g. a series of short beeps), but were limited in overall length to 4 seconds. Figure 1 shows a screenshot of the interface with the signal bar on the right.

Meanings

The meaning space consisted of animal silhouettes facing in two directions. Some meanings were easy to encode iconically while others were more difficult given the medium of communication. For some meanings, both animal type and orientation are easy to express with one holistic, unanalysable signal. As shown in figure 2, an obvious signal for 'eel' just follows its diagonal shape and this immediately makes it clear¹ which one of the two is referred to: high-to-low pitch for the one oriented top-left to bottom-right and low-to-high pitch for the one oriented bottom-left to top-right. Another strategy would be to follow the direction the animal is swimming in. For the eel swimming to the right, this would result in the exact same signal, moving down, but for the eel swimming to the left an iconic signal based on this property would be moving down instead of up, giving this meaning two obvious possible forms that fit well. For the less mappable meanings (the seahorses) there are no such obvious iconic solutions to encode animal type or orientation: a very large number of possible signals could be evaluated as equally fitting.

¹ Assuming a bias for interpreting time as going from left to right, which is most probably the case for people who grew up reading from left to right and looking at left-to-right timelines.

Hard to map

Easy to map

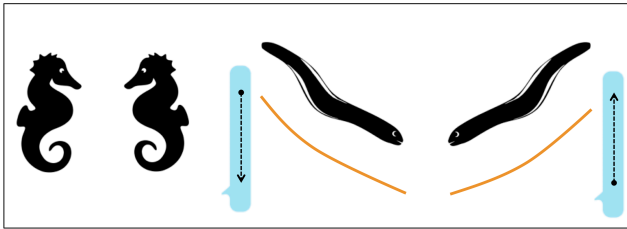


Figure 2: The meanings: ‘hard to map’ seahorses and ‘easy to map’ eels, facing in different directions, with possible iconic signal productions for the eels.

Interaction

Participants played guessing games in which each person held a touch sensitive tablet, both were wearing headphones, and neither could see the other’s screen. The tablets were connected over a network and participants could send each other signals. In each round, one participant was the ‘speaker’ while the other was the ‘listener’. The speaker was presented with a target meaning and produced a signal for it. The listener listened to the speaker’s signal and was presented with a panel showing all the possible meanings. The listener chose one of these meanings as their guess for what the speaker intended. Both players were given feedback after each guess, showing the target meaning and what the listener guessed. Each meaning was presented as the target twice, in a random order, with participants alternating roles as speaker and listener after each presentation, so that each participant took the role of speaker for each meaning once.

Training

Except for each first pair of participants in a transmission chain, both participants were first trained on a language before interacting. In this training they were exposed to each meaning and the last signal used for that meaning by the previous pair. Participants only saw a random half of the previous meanings, and there were two training rounds in total, showing each training item twice. The first pair of each transmission chain started immediately with the interaction phase, thus negotiating their own signals for the meanings.

Procedure

Data for this experiment was collected as part of a science festival². A total number of 202 visitors gave informed consent and participated, resulting in 10 transmission chains. The complete data set has 6 chains with 10 generations and 4 chains with between 3 and 5 generations (we control for these imbalances with the statistical methods below).

² ‘De nacht van kunst en kennis’, Museum Boerhaave, Leiden, The Netherlands

Results

To explore the influence of mappability, learning and transmission on the emerging artificial languages, we analysed communicative success and the use of iconicity.

Communicative success

Communicative success (as measured by correct guesses) was higher for easy to map than for hard to map meanings. This is as hypothesized: the signalling medium affords the iconic expression of those meanings, leading to better communicative performance. The mean correct score was 3.7 out of 8.

As shown in figure 3, meanings in which the animal was facing left were consistently harder to get correct than the ones facing right. This is consistent with the way in which the meaning space was constructed. As noted above, there are two possible iconic solutions for encoding the left-facing eel, whereas these two are conflated in the right-facing eel. The fact that this effect of facing direction occurs for the seahorses as well indicates an interesting connection between signals used for the two types of meanings. We will address this later.

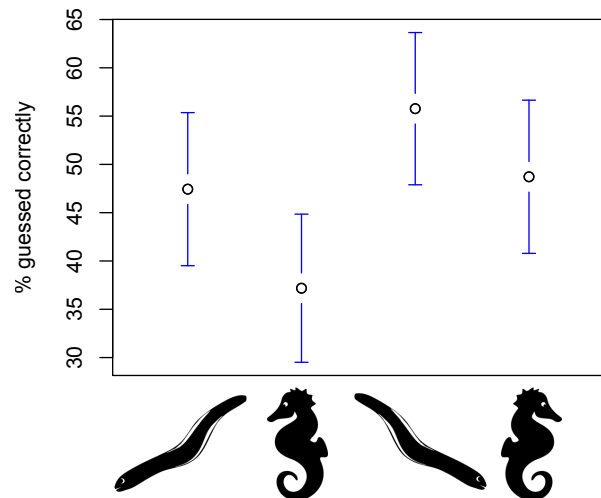


Figure 3: Proportion of correct guesses for each meaning (means and 95% confidence intervals). Expected performance at chance would be 25%.

We analysed the results with a binomial mixed effects model predicting correct guesses by animal, facing direction and generation, while controlling for chain and participant pair. Including animal significantly improved the fit of the model (model comparison $\chi^2 = 5.31$, $df = 1$, $p = 0.02$), as did facing direction (model comparison $\chi^2 = 7.0$, $df = 1$, $p = 0.01$), but generation did not ($\chi^2 = 0.14$, $df = 1$, $p = 0.70$). There were no significant interactions, and no inclusion of random slopes significantly improved the model. That is, facing direction and animal had independent effects.

The model estimates for the probability of correct guesses are: left facing seahorse (35%), right facing seahorse (46%), left facing eel (44%) and right facing eel (56%).

There was no overall effect of generation, although in many cases we can see the system break down after about 4 generations. This could be due to a ceiling effect or other reasons we address in the discussion. Generation does marginally improve the model when looking at only the first 4 generations of each chain ($\chi^2 = 3.54$, $df = 1$, $p = 0.06$).

Iconic signals

We have shown there were differences in communicative success between the different meanings. The pattern of differences fits the hypothesis that participants exploited the fact that some meanings were easier to map iconically given the signalling medium. Can we find evidence for iconicity in the signals? If we look at the mean signal, computed on the basis of all successful signals, we can clearly see the expected pattern for the mappable meanings (Figure 4). The eel swimming to the right has a diagonal shape from upper left to lower right corner and the signal is also predominantly going down in frequency. The opposite pattern is observed for the eel facing left. Again, in line with the fact that there are two competing iconic solutions for the left-facing eel, the effect is strongest for the right-facing eel.

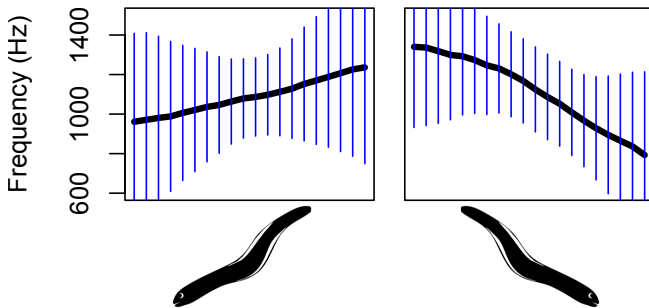


Figure 4: The black lines represent the moving average of signal values over normalised time (x axis) for mappable meanings (shown beneath the graph). 95% of signal segments fall within the vertical blue bars.

We calculated the correlation between the signal trajectory and time. For monotonic, steadily changing tones, an increasing tone would receive a correlation of 1, while a decreasing tone would receive a correlation of -1. We ran a mixed effects model, predicting the correlation of the signal over time by mappability, facing direction and generation, controlling for participant pair and communication chain. Stimuli facing right were more likely to have a negative correlation (est. = -0.20, $t = 1.8$, $\chi^2 = 19.8$, $p < 0.0001$). The effect for right-facing, mappable stimuli (the eel) was especially strong (est. = -0.43, $t = 3.75$, $\chi^2 = 14.1$, $p = 0.0002$), which can be attributed to the mapping for the right-facing eel being unambiguous. There was a weak effect for the interaction between direction and generation (right-facing signals became less correlated over time, est = 0.04, $t = 2.11$, $\chi^2 = 4.47$, $p = 0.03$). As expected there was no

significant effect of mappability (since this test assessed the direction of the signal, est = 0.1, $t = 1.4$, $p = 0.07$). Figure 5 shows the correlation coefficient of the signals, for correct answers, for iconic and non-iconic stimuli.

When the stimuli faces right, regardless of mappability, a correct guess is more likely when the signal has a more negative slope (adding signal direction x facing direction improves fit of the first model $\chi^2 = 4.81$, $t = 0.03$, $p = 0.03$).

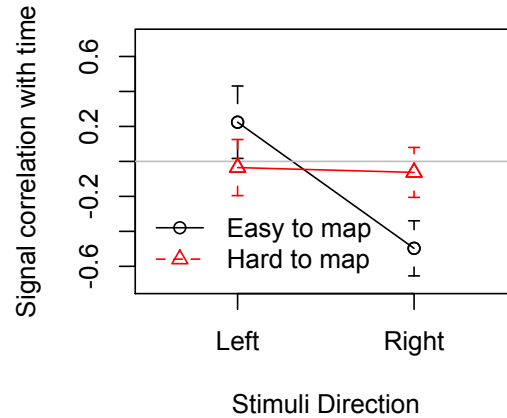


Figure 5: The mean correlation of the signal over time with 95% confidence intervals for different meanings.

Systematic reuse of iconic strategy

Looking at individual languages that emerged across the chains, we observe the reuse and spread of iconic strategies, resulting in systematic patterns in which both animal and facing direction are encoded in a compositional and predictable manner. Often, it seems to be the case that the feature of the signal that encodes the facing direction has its origins in the iconic strategy for representing the eels only, and then got recruited for the seahorses using analogical reasoning. The eel that is positioned from top left to bottom right happens to be right-facing. The most obvious signal for that meaning follows the shape iconically with a decreasing pitch trajectory. This solution can be re-used for encoding the right-facing seahorse, resulting in a signal that is not directly iconic, but understood by analogy. Further extending the analogy, the opposite pattern can be used for the other seahorse. The (often) wobbly signals associated with the seahorses can also be seen as iconic, especially in a system where there is a clear contrast with the smooth signals for the eels. Figure 6 shows four examples of such systems, all from different transmission chains, in which the holistic iconic strategy that works for eel orientation is recruited for representing seahorse orientation.

Figure 7 shows how such a system gradually develops over time as the language is transmitted from dyad to dyad. First, the signals seem to only distinguish the two animals, while making a contrast between the two facing directions, then the distinction in direction appears for eels, which is adopted to encode facing distinction in the seahorses as well one generation later.

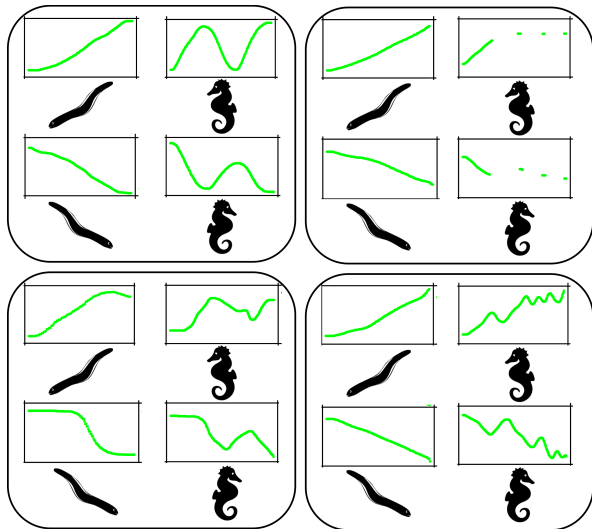


Figure 6: Successful signal sets. Each rounded box represents a separate generation. Signals are plotted as pitch (vertical axis) over time (horizontal axis).

Quantitative support for this mechanism is revealed by the data presented earlier. As shown in Figure 3, there is not only a difference in communicative success for the two eels (which we expect on the basis of their slight difference in mappability), but the right facing seahorse is also easier to guess than the left facing seahorse. This can't be explained by iconic strategies for the seahorses in isolation – there is no theory that would predict that facing left would be harder to map than facing right for these meanings. The difference must come from the signal transferring from the eel to the seahorse. In other words, participants re-use the iconic signals in a compositional way.

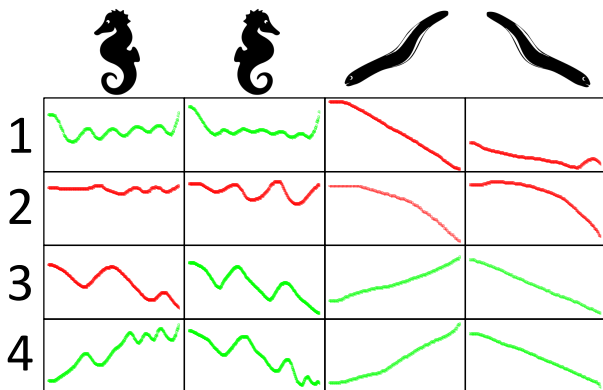


Figure 7: The evolution of signals over generations for different pairs of participants (rows) in the same chain and different meanings (columns) Colour represents successful (green) and unsuccessful guesses (red).

In the experiment above, the first generation did not receive training on a prior language. In this case, iconic signals emerged. However, if conventional signals were to emerge first, it is possible that iconic signals would not appear. To test this, we ran two chains where the first

generation was trained on an arbitrary, non-compositional language that we constructed. Qualitatively, the signals evolve away from the starting languages towards the kinds of languages seen in the main experiment (smooth changes for eels, wobbles for the seahorses). We also observed all the statistical effects presented above with these new chains. Analysing all the data together, neither the proportion of correct guesses nor the signal correlation is significantly predicted by type of starting condition. This suggests that the original arbitrary language is ‘washed out’ by use and transmission.

Discussion

We studied when iconicity emerges in communicative signals and what conditions allow iconic forms to persist. We carefully controlled the medium of communication and the mappability of meanings to this medium. The results show that iconic strategies were used to a great extent and were also reused and combined in a compositional way, resulting in the emergence of systematic iconic patterns.

Where previous work focused on the possible competition between iconicity and (combinatorial) structure (e.g. Verhoef et al., 2013), here we show how iconicity actually shapes emerging structures. Iconicity is used often and iconic primitives become building blocks in compositional patterns. Affordances of the medium of communication direct this process. Our findings fit with the observation that there may be “competition between different types of iconicity that languages exploit in order to organize their grammars” (Meir et al., 2013).

While communicative success improved over the first few chains, we found no overall effect of generation. Some generations solve the problem in the way we expected, but the system was not always transmitted faithfully. This could be caused by the setting of the experiment, the small size of the meaning space, or too little training. Also, the training language came from a random selection of both previous participants' signals, which may disrupt the transmission of the potential structure one of the two participants had internalized and expressed in their signals. In one case, the participants reported not noticing that there was a distinction in facing direction because there was no distinction in the signals from the previous generation. In general, although we designed the stimuli to have an obvious solution, we were surprised at the range of approaches adopted (e.g. iconically representing the animal's speed or size). Some of these systems may be iconic and 'obvious' to their creators, but less easy to interpret by a communicative partner or next learner in the experiment. Our data collection setting limited the experiment to a short length, and therefore a small meaning space. Currently we are working on a laboratory follow-up with a larger variety of meanings and more time for interaction and learning.

Both mappability and learnability influence the emergence and persistence of iconic signals, in our experiment as well as in natural languages. We have shown how iconic signals emerge, become systematised, and how

they may be reused as building blocks in compositional signals, in the process of interaction and transmission. Iterated communication games provide a promising approach towards unravelling the role of iconicity in representation, linguistic structure and language evolution.

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