Experimental insights on the origin of combinatoriality

Gareth Roberts (gareth.roberts@yu.edu)
Department of Psychology, Yeshiva University
2495 Amsterdam Avenue
New York NY 10033 USA

Bruno Galantucci (bruno.galantucci@yu.edu)
Department of Psychology, Yeshiva University
2495 Amsterdam Avenue
New York NY 10033 USA

Abstract

Combinatoriality—the recombination of a small set of basic forms to create an infinite number of meaningful units—has long been seen as a core design feature of language, but its origins remain uncertain. Two hypotheses have been suggested. The first is that combinatoriality is a necessary solution to the problem of conveying a large number of meanings; the second is that it arises as a consequence of conventionalisation. We tested these hypotheses in an experimental-semiotics study. Our results supported the hypothesis based on conventionalisation but offered little support for the hypothesis based on the number of meanings.

Keywords: Experimental semiotics; Human communication; Language.

In the vast majority of languages, a small set of basic meaningless forms (typically phonemes) are recombined to create an infinite number of meaningful units (typically morphemes). This property, which we shall refer to as *combinatoriality*, has been identified as a core design feature of language (Abler, 1989; Hockett, 1960; Hurford, 2002; Jackendoff, 1999; Martinet, 1960; Studdert-Kennedy & Goldstein, 2003). Its origins, however, are unclear.

Explaining combinatoriality

Set-size

Any communication system must employ a set of *signs*: mappings between *signals* (such as vocalisations or manual gestures) and *referents* (the things in the world to which the signals refer). A long-standing explanation for combinatoriality concerns the size of this set. If the signals in the set are distinguished on the basis of analogue contrasts, it will become harder to distinguish them as the set increases in size; restructuring the system in terms of discrete forms is an efficient solution to this problem (Hockett, 1960; Nowak, Krakauer, & Dress, 1999; Studdert-Kennedy, 2000). If this is the case, we should expect combinatoriality to increase as set-size increases.

Mimesis and transparency

Recent research on Al-Sayyid Bedouin Sign Language (ABSL) raises a problem for explanations of combinatoriality based on set-size. ABSL is a fully fledged language, which does not differ substantially from other languages in terms of set-size, but which exhibits very little combinatoriality (Sandler, Aronoff, Meir, & Padden, 2011). Furthermore, while other known sign languages do exhibit combinatoriality, they tend to employ sets of basic forms that are an order of magnitude larger than those employed in spoken languages (Liddell & Johnson, 1989).

Another difference between spoken and signed languages is the degree to which they afford mimesis—that is, the degree to which signals are intuitively motivated by what they refer to. In sign language mimesis is both richer and much more frequent than in speech (Fusellier-Souza, 2006; Perniss, Thompson, & Vigliocco, 2010; Meier, 2002; Taub, 2001).

Sandler et al. (2011) suggested that the beginnings of combinatorial structure in ABSL may be explained by conventionalisation, whereby the signals becomes less transparently mimetic. The ABSL sign for LEMON involves a transparently mimetic signal, in which the signer mimes the act of squeezing a lemon. Since there is more than one way to squeeze a lemon, the form of the signal varies among signers (Sandler et al., 2011, p. 519), but this does not hinder communication so long as the signal remains transparently mimetic. If this transparency is lost, however, the form of the sign can no longer vary to the same extent, but also no longer needs to be constrained by the referent. It is then more efficient to structure signals according to basic sensory-motor constraints, which are best satisfied by a small set of forms (Studdert-Kennedy & Goldstein, 2003).

Two pathways

It should be noted that the two explanations for the emergence of combinatoriality illustrated above are not mutually exclusive. It is possible that the emergence of combinatoriality is related to both set-size and transparency and that there is a complex relationship between the three. Since signs are easier to establish if there is greater opportunity for grounding them in something familiar (Galantucci, 2005; Scott-Phillips, Kirby, & Ritchie, 2009), and transparent signs are by definition grounded, greater transparency should allow rapid growth in set-size, which—as suggested above—may in turn encourage greater combinatoriality. On the other hand, Sandler et al. (2011) explain combinatoriality as a response to low transparency. In other words, there is reason to expect both low transparency and high transparency to lead ultimately to combinatoriality, albeit by different routes. This may go some way to explaining the ubiquity of combinato-

rial structure in the world's languages. Moreover, given that the route from high transparency to combinatoriality is more indirect, it seems likely that combinatoriality takes longer to arise in systems that afford highly transparent signs. This may explain why ABSL still exhibits so little combinatoriality.

Investigating combinatoriality in the laboratory

It is very rare for linguists to have the opportunity to observe and record a new language in its early stages, making such insights as Sandler et al.'s on the origin of combinatoriality very hard to come by. Moreover, new languages tend to emerge in unusual cultural settings, making generalisation difficult. An alternative approach, which has been referred to as Experimental Semiotics, is to study the emergence of novel communication systems under laboratory conditions (Galantucci, Garrod, & Roberts, 2012). Del Giudice (2012) and Verhoef (2012), for example, examined the emergence of combinatoriality in sign systems in diffusion chains, but without any pressure to communicate. Here we present data from a laboratory study in which combinatoriality emerged in sign systems used by pairs of participants to communicate with each other.

Method

Participants   12 pairs of participants (4 female-female; 4 male-male; 4 mixed) participated in the study for course credit or monetary compensation.

The game   Participants played a cooperative guessing game, sitting in separate locations with the same set of four images (henceforth *referents*) displayed in random locations in a 5-by-5 grid on a video monitor (see Figure 1). The game consisted of a series of rounds. In each round, one player would play as "sender" and the other as "receiver". The sender was informed of a target referent and had to convey this referent to the receiver so that the receiver could select it on their screen. If the receiver selected the correct target the round was counted as successful; if not, the round was counted as unsuccessful. Since the players played in separate locations over the internet, they could not speak to each other directly. Instead, the sender could communicate with the receiver exclusively through the use of a digitising pad and a magnetic stylus. The tracings that the sender made on this pad were transformed into on-screen signals in a systematic way: While the horizontal component of the tracings determined the horizontal component of the signal seen on the screen, the vertical component of the tracing was ignored and replaced by a simple downward movement at a constant rate (Figure 2a). The resulting signals were relayed to the screens of both players in real time. Players could not use this pad as an effective drawing or writing device (Figure 2b), even after prolonged practice, and to succeed at the task pairs of players had to cooperatively develop novel forms of communication (Galantucci, 2005).To help them in this, both players received feedback after each selection. Specifically, the receiver was shown what the target image had been and the sender was
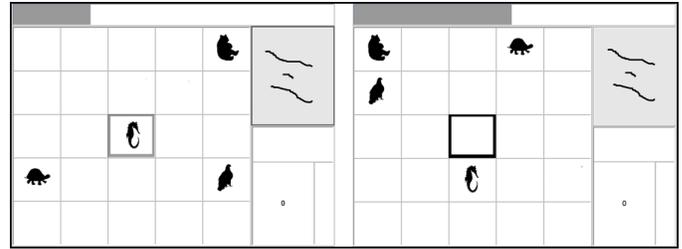
Figure 1: Screenshot from early stage of game. The screen on the left was the Sender's screen; the screen on the right was the Receiver's.

shown which image the receiver had selected. After the feedback phase, the next round began. Players swapped sender and receiver roles after each round.

The referents were presented as targets in a random order: Pairs iterated through four referents twice every eight rounds (in random order). A performance score was kept updated for each referent, based on the proportion of successful rounds in the cycle. If a pair had at least 75% success on each of the four referents, the number of referents in the set was increased to eight, and the cycle length was increased accordingly to 16 rounds. The referent set and cycle length continued to be incremented in this way until either players had mastered a set of 20 referents or two hours of playing had elapsed.
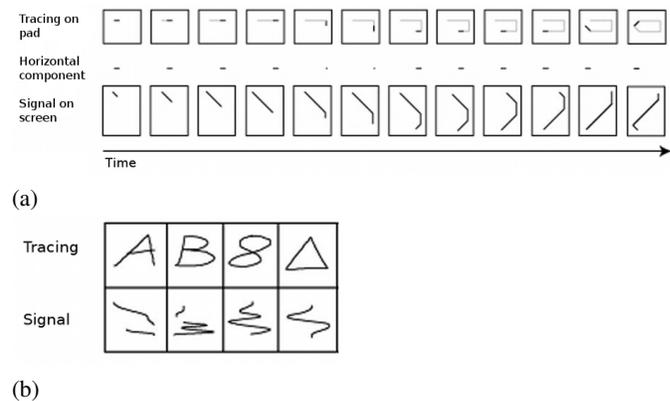
Figure 2: (a) How the drawings players produced on the digitising pad appeared on screen. (b) How common graphic symbols drawn on the digitising pad appeared on the screen

Referents   The referents used were black silhouettes of animals (see Figure 3). These silhouettes afforded the opportunity to develop signals with some degree of transparency, in which, for example, features of the silhouette (e.g. the trunk of the elephant) could be represented by a feature of the signal (e.g. a long curved line). However, the way in which their tracings were transformed did not allow players to reproduce the animal silhouettes or even to create simple drawings. In terms of the hypotheses described above, in other words, it was biased towards relatively low-transparency signals.
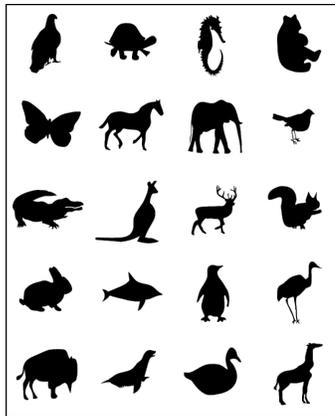
Figure 3: Referents used in the game. The top row shows the referents that were visible to players at the start of the game.

Results

Measures

All of the events in the game were recorded and three measures were derived from this data set: Set-size, Transparency, and Combinatoriality.

Set-size Following the experiment, a sign-set was constructed for each player. This consisted of every referent on which the dyad had reached at least 75% success, paired with the last successful signal the player in question had used to communicate it. The Set-size for a pair was computed as the mean of the Set-sizes for the two players in the pair. The mean Set-size for the 12 pairs was 14.67 (SD = 3.75); the smallest sign-set contained six signs, and the largest contained 20.

Transparency The more transparent the relationship between a signal and a referent, the easier it should be for an independent judge to match them up. Four judges, who had no previous familiarity with the signs or with the purpose of the study, matched signals with referents. This was done as follows. First, the judges gained an understanding of the game by playing a few rounds themselves (as both sender and receiver, with pictures of faces as referents). Then they were shown a display containing one player's signals (as playable videos) along with the referents they referred to. Their task was to match the former with the latter. To give them as much opportunity as possible to detect relationships between signals and referents, judges were permitted to take as long as they liked and to change their minds as often as they liked. Once they had finished, another player's sign-set would appear. (The order in which the sign-sets appeared was randomised.) Each judge evaluated one sign-set from every pair of players (12 sets in total) and every sign-set was shown to two judges. The number of correct matches made by each judge for each player's sign-set provided an indication of the set's Transparency to that judge. This was converted to a z-score by subtracting the mean number of correct matches we
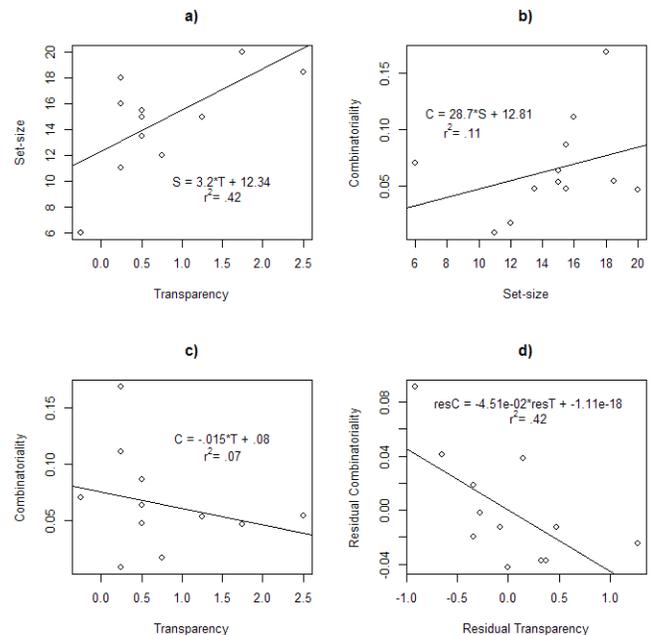
Figure 4: Correlations between: a) Transparency (T) and Set-size (S); b) Combinatoriality (C) and Set-size; c) Transparency and Combinatoriality; d) Transparency and Combinatoriality, with Set-size partialled out.

would expect, for that size of set, by chance and dividing the result by the standard deviation of that mean. Since every player sign-set was rated by two judges, the mean of the z-scores for the two judges was taken as the Transparency index for the set in question. Finally, the Transparency for a pair sign-set was computed as the mean of the Transparency for the two players in the pair. The overall mean Transparency for the 12 pairs was .73 (SD = .76), ranging from $-.25$ to 2.5.

Combinatoriality Combinatoriality was measured using a slightly modified version of the Form Recombination Index used by Galantucci, Kroos, and Rhodes (2010). This measure breaks a sign into forms (parts of a sign divided by empty space). Forms within the sign are then compared with each other to remove duplicates, and the remaining forms are compared with all other forms in the system. The number of matches among these forms is then divided by the total number of comparisons to produce an index ranging from 0 to 1 (where 0 corresponds to a complete absence of Combinatoriality and 1 corresponds to maximal Combinatoriality). A system in which a small number of unique forms are reused many times will have higher Combinatoriality than a system in which a large number of forms are reused little. The mean Combinatoriality for the 12 pairs was .06 (SD = .04), ranging from .01 to .17.

Correlations As can be seen in Figure 4, there was a strong positive correlation between Set-size and Transparency, $r(10) = .65$, $p = .02$, a weak positive correlation between Set-

size and Combinatoriality, r(10) = .33, *p* = .3, and a negative correlation between Transparency and Combinatoriality, r(10) = −.26, *p* = .42. The strong correlation between Set-size and Transparency supports the hypothesis suggested above that more transparent signs are easier to ground, leading sign systems to grow faster. The presence of this correlation, however, poses a problem for interpreting the correlation between Transparency and Combinatoriality. That is, the positive correlation between Set-size and Combinatoriality interferes—via the positive correlation between Set-size and Transparency—with the negative correlation between Transparency and Combinatoriality. We therefore partialed out Set-size from the latter, and this revealed a much stronger correlation, r(9) = −.65, *p* = .01. This result is consistent with the hypothesis that Combinatoriality emerges as a response to low Transparency. The general pattern of results is also consistent with the hypothesis that high Transparency leads to Combinatoriality via Set-size, but the correlation between Set-size and Combinatoriality is too weak to say anything conclusive in this regard.

Conclusion

Theoretical work and research on ABSL suggest two hypotheses to explain the emergence of combinatoriality. The first is that it arises as a solution to the problem of conveying a large number of meanings (Hockett, 1960; Nowak et al., 1999; Studdert-Kennedy, 2000). The second is that it arises as a consequence of conventionalisation, as mimetic signs lose transparency (Sandler et al., 2011). As in other experimental-semiotic studies (Galantucci et al., 2010; Del Giudice, 2012) our analysis of laboratory data did not lend much support to the first hypothesis (although, as suggested by Galantucci et al., 2010, it is possible that set-size exercises an effect on combinatoriality only after some threshold is reached). Our analysis lends the most support to the second hypothesis: Combinatoriality arises when signals lose—or never possess—a mimetic link with their referents.

References

Abler, W. L. (1989). On the particulate principle of self-diversifying systems. *Journal of Social and Biological Structures*, *12*(1), 1–13.

Del Giudice, A. (2012). The emergence of duality of patterning through iterated learning: Precursors to phonology in a visual lexicon. *Language and Cognition*, *4*(4), 381–418.

Fusellier-Souza, I. (2006). Emergence and development of signed languages: From a semiogenetic point of view. *Sign Language Studies*, *7*(1), 30–56.

Galantucci, B. (2005). An experimental study of the emergence of human communication systems. *Cognitive Science*, *29*(5), 737–67.

Galantucci, B., Garrod, S., & Roberts, G. (2012). Experimental Semiotics. *Language and Linguistics Compass*.

Galantucci, B., Kroos, C., & Rhodes, T. (2010). The effects of rapidity of fading on communication systems. *Interaction Studies*, *11*(10), 100–111.

Hockett, C. F. (1960). The origin of speech. *Scientific American*, *203*, 88–96.

Hurford, J. R. (2002). The role of expression and representation in language evolution. In A. W (Ed.), *The transition to language* (p. 311-334). Oxford: Oxford University Press.

Jackendoff, R. (1999). Possible stages in the evolution of the language capacity. *Trends in Cognitive Science*, *3*(7), 272–279.

Liddell, S. K., & Johnson, R. E. (1989). American sign language: The phonological base. *Sign Language Studies*, *64*, 195–278.

Martinet, A. (1960). *Elements of general linguistics*. Chicago: University of Chicago Press.

Meier, R. (2002). Why different, why the same? explaining effects and non-effects of modality upon linguistic structure in sign and speech. In R. Meier, K. Cormier, & D. Quinto-Pozos (Eds.), *Modality and structure in signed and spoken languages* (pp. 1–25). New York: Cambridge University Press.

Nowak, M. A., Krakauer, D. C., & Dress, A. (1999). An error limit for the evolution of language. *Proceedings of the Royal Society of London Series B-Biological Sciences*, *266*(1433), 2131–2136.

Perniss, P., Thompson, R. L., & Vigliocco, G. (2010). Iconicity as a general property of language: Evidence from spoken and signed languages. *Frontiers in Psychology*, *1*, 1–15.

Sandler, W., Aronoff, M., Meir, I., & Padden, C. (2011). The gradual emergence of phonological form in a new language. *Natural Language & Linguistic Theory*, *29*(2), 503–543.

Scott-Phillips, T. C., Kirby, S., & Ritchie, G. R. S. (2009). Signalling signalhood and the emergence of communication. *Cognition*, *113*(2), 226–233.

Studdert-Kennedy, M. (2000). Evolutionary implications of the particulate principle: Imitation and the dissociation of phonetic form from semantic function. In C. Knight, M. Studdert-Kennedy, & J. R. Hurford (Eds.), *The evolutionary emergence of language* (pp. 161–176). Cambridge: Cambridge University Press.

Studdert-Kennedy, M., & Goldstein, L. (2003). Launching language: The gestural origin of discrete infinity. In S. Kirby & M. H. Christiansen (Eds.), *Language evolution* (pp. 235–254). Oxford: Oxford University Press.

Taub, S. F. (2001). *Language from the body*. Cambridge: Cambridge University Press.

Verhoef, T. (2012). The origins of duality of patterning in artificial whistled languages. *Language and Cognition*, *4*(4), 357–380.