The Oxford Handbook of Approaches to Language Evolution

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https://doi.org/10.1093/oxfordhb/9780192886491.001.0001

Published online: 22 May 2025 **Published in print:** 29 May 2025 **Online ISBN:** 9780191981593

Print ISBN: 9780192886491

CHAPTER

3 Communication experiments: Social interaction in the formation of novel communication systems

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https://doi.org/10.1093/oxfordhb/9780192886491.013.4 Pages 41–62

Published: 22 May 2025

Abstract

By studying communicative interactions between humans, we can investigate the basic processes underlying the evolution of language, including how humans manage to communicate in the first place, how they form novel conventions, how they create grammatical structure, and subsequent changes to their conventions and grammar. Communication experiments, which involve interactions between two or more human participants in artificial settings, are a useful method for addressing these questions within a controlled environment. These experiments can help researchers with teasing apart the effects of different variables on the emergence of language, which are typically confounded in naturalistic settings. In this chapter, we first briefly review the history of communication paradigms. We then summarize the procedures, designs, and typical measures that characterize communication experiments. Finally, we discuss the theoretical limitations and methodological challenges of using such paradigms and propose some ways forward.

Keywords: communication games, experimental semiotics, language evolution, language emergence, social interaction, referential communication, director–matcher task, experimental design

Subject: Language Evolution, Linguistics

Series: Oxford Handbooks

Collection: Oxford Handbooks Online

Language is used for communication, i.e. people converse with each other to transmit information (Shannon and Weaver 1949) and exchange their cognitive states with others (e.g. Sperber and Wilson 1994). For example, in a day-to-day conversational situation between two people at a dinner table, one interlocutor might say, ‘pass me the salt’. Their conversation partner would then pick the salt shaker from the various objects they can see on the table and pass it over. For this communicative interaction to function, interlocutors should be aligned on

shared representations (Garrod and Pickering 2004) situated in their concurrent conversational context (e.g. 'the salt' referring to the shaker, not individual grains of salt; and to the shaker on our dinner table, as opposed to our neighbours' table in a restaurant; Clark 1996). These individual interactions are a basic unit in which language is used and, consequently, changes: interlocutors need to establish novel shared conventions (defined as arbitrary solutions to repeated coordination problems; Lewis 1969) for newly emerging concepts, and they can modify existing conventions in novel ways (Höfler and Smith 2009; Smith and Höfler 2015). From these dyadic micro-level changes, macro-level cultural change can arise via diffusion within a language community and via transmission to new learners (see also Chapter 1, this volume). But how do local conventions form to begin with? What pressures and processes operate during communication, and how do they shape emergent languages?

The empirical investigation of human communication and its emergence is a fruitful venue for language evolution research. In this chapter, we summarize the methodological approach of using *communication experiments* to study language evolution. We define a communication experiment as any experimental study
p. 42 involving two or more human participants, whose success in the task depends on signalling some crucial ↳ information. This means we will not consider work on animal communication (see Part III in this volume) or computer simulations (see Part II in this volume) here. We start by providing a brief history of communication experiments (section 3.1), acknowledging classic experiments on natural language use. After this, we outline the most prominent methodological variations within communication experiments focusing on language evolution (section 3.2), including a more detailed description of two case studies focusing on the emergence of conventions within shared context and on the effect of social structure on the emergence of grammar. Lastly, we highlight the potential challenges and pitfalls of the method, focusing on participants' existing prior knowledge and the lack of data from children (section 3.3).

3.1 A short history of communication experiments

There is a long tradition of using communication experiments to explore language use, coordination, conventionalization, and—more recently—evolution. In the most standard and simple version of these experiments (see also Lewis game, Chapter 17, this volume), there is some set of stimuli (the referents) that participants need to communicate about in order to succeed. These setups are typically known as *referential communication games* or *director–matcher experiments*. In their most typical version (Figure 3.1), a pair of participants communicates about a target meaning, with one person being the sender (also referred to as the director or the producer), and the other participant being the receiver (also referred to as the matcher or the guesser). The sender needs to convey this target meaning (e.g. shape, location on a grid, etc.) in some way (e.g. using their native language, pantomime, artificial language, etc.) to the receiver, and the receiver needs to select the correct target (typically from a set of distractors).

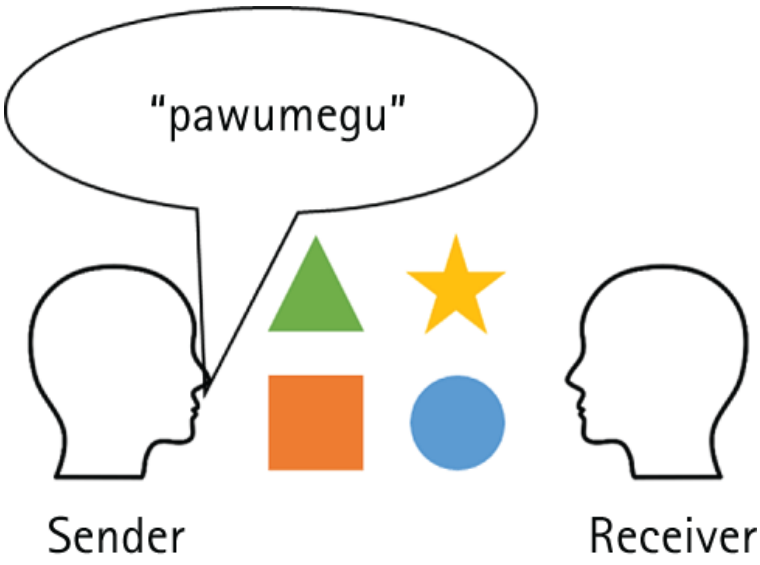

Figure 3.1 A basic referential communication task.

The sender needs to convey a target meaning (e.g. the triangle) to the receiver in some way (here, with a pseudoword).

When participants solve the task using natural language, the respective studies can be considered part of a field known as *experimental pragmatics* (for an overview, see e.g. Noveck 2018). Research in experimental pragmatics
p. 43 can tease apart the role of pragmatic ↳ mechanisms contributing to language use by controlling and manipulating different features of the task, such as feedback, the task environment, and more. A very early example of the basic referential communication task is the series of experiments by Krauss and Weinheimer (1964, 1966, 1967), which showed that phrases used by senders to refer to visual stimuli tend to get shorter over the course of repeated conversations (Krauss and Weinheimer 1964), when receiving direct feedback from receivers or the experimenter (1966), and when stimuli are more dissimilar (1967). Clark and colleagues ran a similar task on participants' descriptions of unfamiliar *tangram* figures. These studies showed how people minimize communicative effort to—again—produce shorter phrases (Clark and Wilkes-Gibbs 1986), such that people overhearing the descriptions (but not directly participating) have a hard time understanding them (Schober and Clark 1989; Wilkes-Gibbs and Clark 1992). More recently, such paradigms have been used to investigate multimodality and the alignment of not only speech, but also gesture and manual expressions (Rasenberg, Pouw, et al. 2022; Rasenberg, Özyürek, et al. 2022).

Another classic task was created by Garrod and Anderson (1987) in the form of the 'maze game', in which participants converse in natural language to coordinate on opening barriers within a virtual maze. Results from this task emphasized the creation of local conventions between interacting participants (Garrod and Anderson 1987), e.g. by aligning on references that describe the maze via counting rows and columns. Garrod and Doherty (1994) extended this paradigm and showed that a closed community of participants will converge on shared global conventions, while isolated pairs and chains with new participants will remain relatively flexible (but also less coordinated) in their descriptions. In a recent application of the task, Nölle et al. (2020) varied the structures of the mazes and showed that linguistic adaptations were also affected by the task environment.

These examples of communication experiments already touch upon language evolution by showing how language use adapts over the course of conversation, and their novel stimuli require participants to develop new shared references. However, their reliance on natural language prevents these studies from investigating how communication can emerge in the first place, and new references developing within the system of an existing language are already greatly supported and biased by that language. The same issue applies to a related paradigm asking participants to learn novel words (together or separately) before communicating (Wu and Keysar 2007; Heller et al. 2012).

While experimental pragmatics can tell us how existing language adapts and functions in different scenarios, *experimental semiotics* makes use of communication experiments where participants are not allowed to use their native language, and instead are required to develop novel signalling systems (e.g. using gestures, drawings, vocalizations; see section 3.2.1 below) in order to communicate. Since this key innovation can inform us more clearly about language evolution, we will focus on experimental semiotics from now on. Experimental semiotics explores questions related to the formation of communication systems and is concerned with (a) how and why communication and novel conventions emerge and evolve, as well as (b) what shape and structure
p. 44 new conventions take. Examples for (a) include studies examining how the ↳ emergence of conventions is affected by age (Bohn et al. 2019; Kempe et al. 2019), modality (Macuch Silva et al. 2020), or the role of shared context for emergent communication (Winters et al. 2018; Müller et al. 2019). Studies concerned with (b) investigate, for example, the form of signals when participants can repair misunderstandings (Garrod et al. 2007; Healey et al. 2007; Fay et al. 2018a) or under which social conditions people develop different types of signalling systems (Kirby et al. 2015; Motamedi et al. 2019; Raviv et al. 2019, 2020; Segovia-Martín et al. 2020). While an exhaustive review of the field of experimental semiotics is outside the scope of the current chapter (see e.g. Scott-Phillips and Kirby 2010; Galantucci and Garrod 2011; Galantucci et al. 2012; Tamariz 2017; Nölle et al. 2022; Delliponti et al. 2023), below we characterize some of the main themes within the field of experimental semiotics, focusing on methodological choices and experimental design.

3.2 Methodological choices in communication experiments

In the standard procedure of referential communication experiments, two or more participants need to interact repeatedly over several rounds of experimental trials, either face-to-face or via computer interface. Two key features of the task are the *meaning space* (i.e. what people need to communicate about) and the *signalling space* (i.e. in which form participants can communicate). During the communication experiment, participants need to map signals to meanings in a way that allows for mutual understanding. In this section, we outline many of the possible methodological variations of communication experiments in design, stimuli, and procedure, while also explaining the implications of varying these features.

3.2.1 Signalling spaces

Experimental semiotics makes participants communicate by using signals that are not *a priori* established, allowing researchers to study the formation and evolution of novel conventions instead of the use or change of established ones. The *signalling spaces* used in communication experiments can be extremely diverse and innovative and situated within different modalities. For example, participants might be asked to communicate via written letters and pseudowords (Selten and Warglien 2007; Roberts 2010; Kirby et al. 2015; Carr et al. 2017; Tamariz et al. 2018; Raviv et al. 2019), silent gestures (Christensen et al. 2016; Nölle et al. 2018; Motamedi et al. 2019; see also Chapter 9, this volume), free drawing (Galantucci 2005; Garrod et al. 2007; Healey et al. 2007; Fay et al. 2010; Galantucci et al. 2010; Fay et al. 2018a, b), pre-constructed graphical signs (Morin et al. 2022; Müller
p. 45 et al. 2019, 2021; Murthy et al. 2022), vocalizations (Perlman et al. ↳ 2015; Perlman and Lupyan 2018), the pitch of auditory signals (Verhoef et al. 2015; Little et al. 2017), virtual movements of participants (Newman-Norlund et al. 2009; Scott-Phillips et al. 2009; de Ruiter et al. 2010; Müller et al. 2023), or even tactile stimulations (Iizuka et al. 2013).

Across modalities, signals can be discrete (as in the case of the use of pre-existing alphabets to construct pseudowords) or continuous (as in the case of silent gestures and auditory pitch). In addition, the signalling space might be constrained in some way: for example, Raviv et al. (2019) only allowed participants to create pseudowords using ten consonants and five vowels, and Scott-Phillips et al. (2009) only allowed participants to move horizontally and vertically, but not diagonally. Other studies have left the signalling space wide open

(Garrod et al. 2007; Healey et al. 2007; Fay et al. 2018a), for instance by letting participants draw freely on a whiteboard. Limiting the signalling space can have important implications for communication: for instance, Selten and Warglien (2007) found that smaller signal repertoires made emergent communication harder. It is important to design signalling spaces in line with task demands, and make sure the space is sufficiently expressive. A few studies have specifically investigated the effect of signalling modality by comparing the use of vocalizations against gestures (or both) within the same experiment (Fay et al. 2013, 2022; Macuch Silva et al. 2020; Lister et al. 2021). Results from such studies typically show that communicative success is higher for gestures compared to vocalizations, often thanks to the high degree of iconicity in the manual modality. This has potential implications for the ongoing debate about the origins of language being gestural, vocal, or multimodal.

One important design choice is whether, prior to communication, novel signals are first provided and taught to participants in an individual training regime, or whether participants are not given any initial input and are free to explore a signalling space as they please. In the case of pre-training, participants are taught predetermined signal-to-meaning mappings (which can be completely random or already carry some systematic structure), which they need to memorize during multiple rounds of exposure before they can interact with their partner(s). In the case of no pre-training, participants start communicating immediately and need to construct their first signals from scratch. The former approach can be useful if the focus is on the changes to a controlled signalling system introduced by communication (e.g. Kirby et al. 2015) or individual differences (e.g. Josserand et al. 2024), while the latter approach has been used to study the emergence and conventionalization of novel signals from scratch (Galantucci 2005; Garrod et al. 2007; Motamedi et al. 2019; Müller et al. 2019; Raviv et al. 2019).

3.2.2 Meaning spaces

The *meaning spaces* used in communication experiments (i.e. the set of referents that participants need to communicate about) also vary greatly across studies. Some studies use auditory stimuli such as music pieces (Healey et al. 2007) or environmental sounds (Macuch Silva et al. 2020), while others have used written words
p. 46 denoting ↳ familiar concepts (Garrod et al. 2007; Fay et al. 2010; Perlman et al. 2015; Fay et al. 2018a; Motamedi et al. 2019; Murthy et al. 2022). However, visual stimuli are by far the most commonly used meanings. Stimuli can vary in their degree of complexity: from communicating about familiar shapes such as squares and circles (e.g. Iizuka et al. 2013) or different colours (Roberts et al. 2015; Müller et al. 2019, 2021; Morin et al. 2022), to communicating about the positions and orientation of known shapes (e.g. Newman-Norlund et al. 2009; de Ruiter et al. 2010), to communicating about more complex unknown images (e.g. Raviv et al. 2019; Macuch Silva et al. 2020), cartoon figures (Nölle et al. 2018), and even full visual scenes depicting multiple agents performing actions (Schouwstra and De Swart 2014; Christensen et al. 2016; Schouwstra 2017). The latter can be a static image or even a dynamic video depicting movement and actions.

Carefully designed meaning spaces—together with appropriate signalling spaces—have the potential to inform us about the origins of structure in natural language. Oftentimes, meaning spaces are structured to some extent, containing different combinations of features (semantic dimensions) such as shape, size, colour, motion, texture, etc., or internal categories such as professions, places, and objects (e.g. Kirby et al. 2015; Nölle et al. 2018; Tamariz et al. 2018). The idea behind using structured meaning spaces is that participants' emerging communication systems should map to fit this internal structure by creating signals that express different categories (e.g. having a part-word for describing the shape, and a part-word for describing colour). For example, Kirby et al. (2015) used a meaning space containing four discrete shapes appearing in four different fill patterns, and Nölle et al. (2018) used a meaning space containing cartoon characters that could be classified into categories based on gender, profession, and whether or not they own a pet. Meaning spaces can also be composed of combinations of more abstract semantic dimensions such as themes and temporal concepts (Motamedi et al. 2019; Verhoef et al. 2022). For example, Verhoef et al. (2022) asked participants to describe

meanings representing different temporal periods ('day' vs. 'year') along three different categories (duration, sequence, deictic), and Motamedi et al. (2019) used a meaning space containing six different themes (e.g. food, religion, music, photography) that could appear in four different categories (people, locations, objects, and actions). While most meaning spaces contain discrete concepts or combinations thereof, stimuli can also be continuous: for example, Carr et al. (2017) used different types of triangles generated by varying the location of three points on a grid to create a continuous, open-ended meaning space.

Communication experiments that do not merely ask for referential communication, but are *coordination games* instead (see Galantucci and Garrod 2011), pose a particular challenge regarding the meanings in the task. Here, participants have to not only find mappings between the signals and meanings, but also agree on what common meanings they want to refer to in the first place. In other words, while success in a referential experiment is achieved by finding shared signals for a pre-defined referent (the 'target'), in a coordination game, participants have to reach a common goal by finding useful referents plus the signals for them; this is closer to the semiotic challenge encountered in real-life communication. One example of this is experiments
p. 47 based on Galantucci ↳ (2005), in which the participants' goal is to move to the same room in a virtual space; but to do so, they also have to agree on what exactly should be communicated about locations. For instance, some pairs in Galantucci (2005) converged on signals that numbered the different rooms in the space, some pairs referred to visual icons associated with different rooms, and other pairs described the longitudinal location of the player in the virtual space.

Some experiments have made the impact of the meaning space their object of investigation and systematically manipulated it, focusing on emergent structure in the signals. For example, Selten and Warglien (2007) showed that a growing meaning space led to the evolution of more compositional structure in the signals to meet the demands of communicating new referents. Similarly, Nölle et al. (2018) found that a more open (i.e. not limited to a small set of referents) meaning space led to higher systematicity in gestural signals. They also showed that functionally adaptive structure in the meaning space (i.e. what feature of a referent mattered for accurate discrimination) was reflected in emergent signal structure. A few studies also considered how particular meanings can afford iconic signals to develop, affecting internal signal order (Christensen et al. 2016) or preventing the emergence of combinatorial signals (Roberts et al. 2015). Lastly, more frequently occurring meanings have shown to lead to shorter signals when there is pressure to communicate accurately and efficiently (Kanwal et al. 2017), and signal order tends to conventionalize towards the most frequent order in the meaning space (Christensen et al. 2016). Taken together, these examples illustrate that it is important to choose a particular meaning space in line with task demands, as it will impact communication and the resulting signals majorly. For our understanding of language evolution, they show how language can be shaped by the meanings that interlocutors are trying to communicate.

3.2.3 Feedback and repair

Communication experiments also vary in the amount of *feedback* that participants receive. We use this term to specifically refer to information received periodically after a trial in the task has ended. Providing full feedback would mean that all participants receive information not only about success or failure, but also about what choice was made regarding the referents (e.g. Raviv et al. 2019, 2020). Partial feedback can leave out this information on choices (e.g. Healey et al. 2007; Moreno and Baggio 2015), limit information to only one participant, or even obfuscate the feedback on performance by only providing the average performance over a block of trials (e.g. Müller et al. 2021; Morin et al. 2022). Feedback is a straightforward design choice to calibrate the difficulty of a task, but not many communication experiments have investigated its impact on language evolution directly. A notable exception is the study by de Ruiter et al. (2010), which ruled out that senders are merely 'dictating' encoding strategies to receivers by showing that communication improved when feedback was available. Importantly, providing extensive feedback can change the interpretation of a communication
p. 48 experiment because ↳ signal–meaning associations can arise from repeated trial and error reinforced by the feedback. If a study is concerned with the emergence of communication from scratch, this can be a potential confound, which has led some studies to forgo feedback completely (e.g. Iizuka et al. 2013; Fay et al. 2018a; Müller et al. 2019).

A design choice related to feedback is whether participants in the task are able to *repair* misunderstandings that might arise, which is a ubiquitous phenomenon in natural language (Dingemanse et al. 2015). The term is sometimes used interchangeably with 'feedback' in the literature, but we want to keep the two clearly separate. The key difference for us is that repair gives participants themselves the option to indicate (mis)understanding (for example, think of interjections like 'sorry?' or 'uh-huh' in English) and potentially mend it, whereas feedback is provided by the experimental design (note that a similar distinction was already made by Krauss and Weinheimer in 1966, albeit in a task involving natural language). Implementation-wise, communication experiments can give pre-defined repair signals to participants (Müller et al. 2019) or they can simply let them interact freely with one another in games with open signalling spaces (Garrod et al. 2007; Healey et al. 2007; Fay et al. 2018a) to, for example, 'tick' solutions they understood. Repair can be a helpful option for participants while adding to the ecological validity of the task. However, previous research focused on repair by itself (Garrod et al. 2007; Healey et al. 2007; Fay et al. 2018a) has only found minor improvements in communicative success, while showing benefits for developing more abstract signals, i.e. signals that are less iconic, more simplified, and harder to understand for outsiders. Garrod et al. (2007) also showed that this symbolification happened faster when repair was concurrent, as opposed to after drawing had already finished.

3.2.4 Sender and receiver roles

Regardless of the amount and manner of feedback or repair, the basic interactions between participants can also differ fundamentally in the way *sender/receiver roles* are assigned. A typical design is to only provide information about the correct referent to one participant at a time and ask them to produce signals, while the other participant tries to understand and choose. To keep these roles controlled, they can either stay the same for the entirety of the experiment, which means communication is inherently asymmetric and the receiver is limited to a reactive role; or participants can alternate and switch roles. The latter is arguably more interactive and realistic given the turn-taking structure of natural language (Sacks et al. 1974), but the former can be useful to keep the challenges of sending/receiving separate. In fact, role asymmetry can be beneficial for language evolution because it means only one side has to coordinate if a task can be solved by 'dictating' an arbitrary code to the receiver (Selten and Warglien 2007; Moreno and Baggio 2015). Alternatively, both participants can also be tasked with signalling and understanding at the same time. This is frequently the case in coordination games, where oftentimes the turn-taking structure itself (or, in fact, what constitutes a turn) is
p. 49 not even defined, but has to be organized by the participants ↳ themselves (e.g. Galantucci 2005; Scott-Phillips et al. 2009). Such a design increases the ecological validity, but also the communicative challenge of the task. A few studies have also considered the performance of 'overhearers', i.e. participants that did not participate in the original interactions of an experiment. Overhearers end up with less accurate, less efficient, and less aligned communication (Fay et al. 2018a), and performance is particularly bad when they cannot observe signals from the early stages of communication (Garrod et al. 2007). However, iconicity can help overhearers with understanding the original signals (Perlman et al. 2015; Perlman and Lupyan 2018). Ultimately, investigating the roles that participants take on in communication experiments can inform us about what makes a resulting 'language' shared.

3.2.5 Case study 1: Communicative contexts

Referents are usually shown in contrast with other options to pose a communicative challenge. As a real-life analogue, imagine standing in front of a shelf at the supermarket while being told to 'get the orange juice', which is next to other juice boxes, bottles of water, etc. These communicative *contexts* are dependent on the meaning space, but they can be varied separately even within one constant meaning space. A straightforward contextual variation is that increasing the number of referents can make communication about these referents harder. Notably, this affects both the sender (who has to signal more precisely to denote a referent from a larger context) and the receiver (who has to pick from a larger context) in the experiment. But also the distance between referents can affect the difficulty in a similar vein (e.g. more similar vs. less similar colours). A number of communication experiments have manipulated the communicative context to show how it affects language evolution. Similar to the results for meaning spaces, some studies showed that the relevant dimensions within contexts will also change how signals get structured (e.g. Winters et al. 2015, 2018). Murthy et al. (2022) manipulated the variability of participants' prior associations within contexts, showing that contexts with well-aligned priors are easier to coordinate on. Manipulating contexts also allows for varying the information that is shared between participants in any given trial. In line with classic theories of communication (e.g. Grice 1989; Sperber and Wilson 1994; Clark 1996), more shared information between participants is associated with better performance during communication (de Ruiter et al. 2010; Winters et al. 2018; Müller et al. 2019).

We present the study by Müller et al. (2019) in more detail here. This study used the same referential communication task in two experiments to investigate the impact of shared information on emergent communication. Participants were asked to communicate the correct colour from an array of four colours by using pre-constructed graphic symbols. These symbols were black-and-white and chosen to be ambiguous regarding their association to the colour space in the task (Figure 3.2a). Participants were enabled to repair potential misunderstandings via pre-defined written annotations that were introduced to them before the
p. 50 experiment, but received no feedback from ↳ the experimental design itself. The shared visual context

between participants in both experiments was manipulated by restricting the sender's access to only one colour (the target) from the array the receiver had to choose from (Figure 3.2b). The results of both experiments showed that participants' emergent communication benefitted from the senders' access to the context. Performance also improved over time, suggesting participants were gradually establishing local conventions. Moreover, switching to a different meaning space in the second half of Experiment 2 revealed that participant pairs benefitted from reusing their existing conventions only when they had had access to the shared context before, suggesting that those communication systems were more flexible.

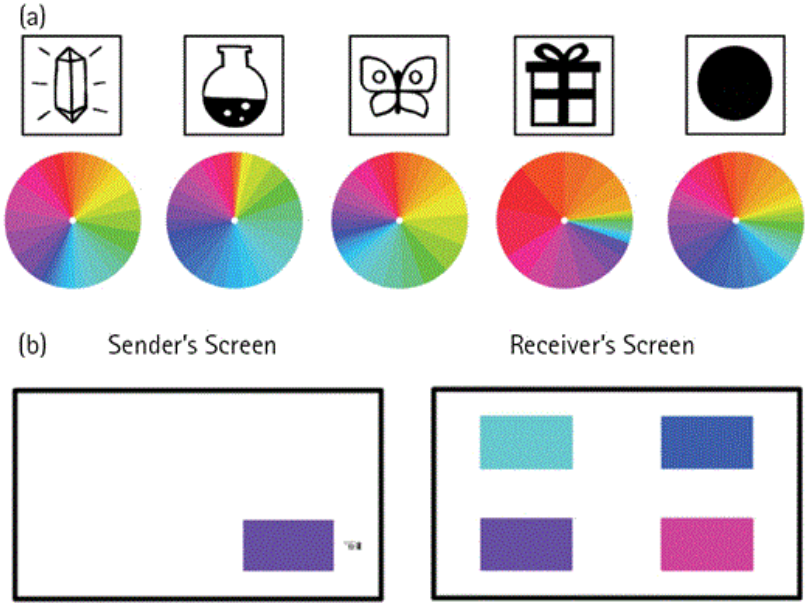

Figure 3.2 Case study on shared visual context.

Panel (a) shows five examples of black-and-white symbols that participants could use to communicate about different colours, along with their corresponding mapping to colours as reported by senders in Experiment 2 in Müller et al. (2019). The area occupied by a colour corresponds to the number of reported uses for that colour. The figure shows large variance across senders, suggesting sufficient ambiguity of the black-and-white symbols; but also patterns specific to individual symbols, like a wide blue-green association for the second symbol or a concentration on the red area for the fourth one. Panel (b) shows an example screen from the 'unshared visual context condition'. In the 'shared' condition, the sender would see all four colours instead, arranged randomly. *Source*: adapted with permission from Müller et al. (2019); reproduced under a CC BY-NC license.

3.2.6 Case study 2: Social structure

Communication experiments can also be used to study the relationship between language evolution and the social environment in which languages evolve. This is done by manipulating the number of interacting participants (e.g. Fay et al. 2008, 2010; Raviv et al. 2019) and/or the degree of connectivity between participants (e.g. Raviv et al. 2020; Segovia-Martín et al. 2020). Since the classic communication experiment is dyadic in nature (i.e. featuring a sender and a receiver), social structure variations are typically implemented by splitting
p. 51 groups into pairs and having participants switch ↳ partners from time to time. While one-to-many interactions are easy to implement (e.g. one participant sends a signal to multiple members of the group, who need to guess it), they introduce an asymmetry in production and comprehension that is often unwanted. They can also substantially speed up the process of convergence and thus hinder our ability to see how individual interactions build up to population-level phenomena.

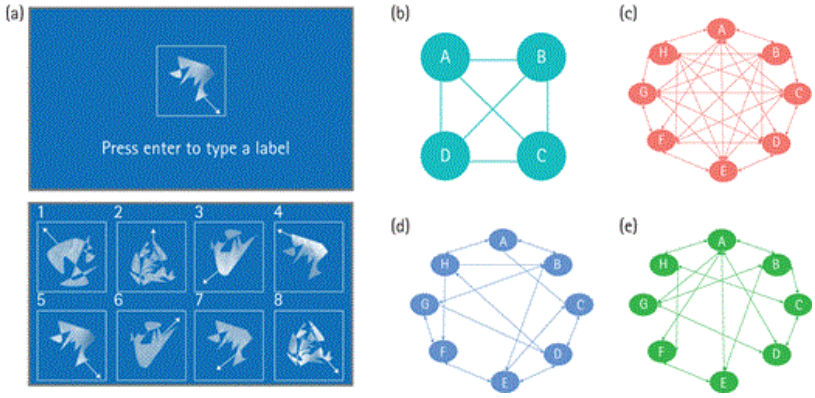

Figure 3.3 Case study on the role of social structure using a group communication paradigm.

Panel (a) shows the sender's and receiver's screens, respectively. Raviv et al. (2019) tested the effect of community size by comparing fully connected groups of four (b) or eight (c) participants, and Raviv et al. (2020) tested the role of network structure by comparing groups of eight participants that were either fully connected (c), small world (d), or scale free (e).

Source: Adapted from Raviv et al. (2020); reproduced under a CC BY license.

Zooming in on the role of the social environment, Raviv et al. (2019) tested the effect of community size in the formation of artificial languages using the 'group communication game'. In the study, different-sized groups needed to use written pseudowords to communicate about a set of novel scenes, which combined discrete shapes with continuous motion by having shapes move in an angle from a 360 degree range (Figure 3.3). Groups were composed of either four or eight participants in order to evaluate whether bigger groups would create more structured languages—a prediction motivated by cross-linguistic studies and theories of language change which suggest that languages spoken in big communities tend to have more systematic and transparent grammars (Wray and Grace 2007; Trudgill 2008, 2009; Lupyan and Dale 2010). The results of this study showed that larger groups developed more compositional languages over time, and did so faster and more consistently than small groups. Larger groups were seemingly under a stronger pressure to generalize their languages and favour systematic variants, which could, in turn, ease mutual understanding and facilitate convergence. Moreover, results showed that small groups varied more in their linguistic behaviours, while larger groups behaved relatively similarly to each other. Together, the results of Raviv et al. (2019) show that community size had a unique and causal influence on the formation of new languages.

p. 52 A similar design was used in Raviv et al. (2020) to test the role of network structure, that is, what happens when groups are of the same size, but their degree of density and connectivity is manipulated. Specifically, Raviv et al. (2020) compared communication in fully connected networks (in which all participants interact with each other), small-world networks (where some participants never directly interact, but are still indirectly linked by a short chain of shared connections), and scale-free networks (which are similar to small-world networks in terms of sparsity, but where the distribution of connections follows a power law: such that most participants only interact with a few people, yet some—the 'hubs'—interact with nearly everyone in the group). Results showed that in such relatively small groups, the exact architecture of the network did not significantly affect the evolution of new languages: all networks developed languages that were highly systematic and compositional, communicatively efficient, stable, and shared across members. However, small-world networks showed the most variance in behaviour—suggesting that such networks may be more sensitive to random events (i.e. drift), potentially because frequent interactions among small subgroups can preserve random behaviours more easily.

Finally, communication experiments can also be combined with iterated learning paradigms (see Chapter 1, this volume), incorporating both interaction and transmission across multiple 'generations' of communication pairs (e.g. Kirby et al. 2015; Motamedi et al. 2019) or groups. In such setups, the final communication systems

created by the first dyad or group (i.e. their signal-to-meaning mappings in the last communication round) become the input for the next dyad or group in the chain, and so on for multiple iterations. This can help disentangle the effects of transmission from the effects of communication and show the unique contribution of each process.

3.2.7 Practical considerations and measures

We have alluded to the communicative challenge of the task several times already when discussing individual methodological choices, but task difficulty ultimately is a result of the combination of all these features, interacting with one another. If communication in the experiment turns out to be trivial or impossible to achieve, this can mask important effects, as differences between participants might be hard to obtain. However, failures to communicate can also be insightful and an indication that a feature that is core to the emergence of communication might be missing from the task, or from the approach that participants are taking to it (Galantucci and Garrod 2011).

Communication experiments can be either face-to-face or online, with or without a computer interface (see section 3.3). The data from such experiments typically include a record of the target item, the distractor items, the selected items, matching accuracy, sender and receiver identity, trial number and round number, accompanied by a record of the signal used for communication (e.g. in written form in case of pseudowords, or using video/audio recording for gestures and vocalizations).

p. 53 Depending on the objectives of the study, researchers can analyse the changes to the emergent communication systems over time based on parameters such as communicative success (typically binary, indicating whether the target item was guessed correctly or not), signal length (e.g. the number of characters in a pseudoword or the duration of a gesture), iconicity of the signal (i.e. how easy it is for naive participants to guess the meaning of the signal), the degree of convergence between participants (i.e. how similar are the signals produced by different participants for the same meaning) or within participants (i.e. how stable are signals used by the same participant over time), and the degree of systematic structure and/or complexity of the signals. The latter measure is typically of great interest to language evolution researchers as it may indicate the emergence of grammar during communication, and it can be quantified in multiple ways: for example, by using topographic similarity in form–meaning mapping (e.g. Kirby et al. 2008, 2015; Nowak and Baggio 2016), conditional entropy (e.g. Winters et al. 2015), or the form combination index (e.g. Roberts and Galantucci 2012).

3.3 Common challenges for communication experiments

In this section, we focus on challenges specific to communication experiments that are beyond the general limitations of experimental work. First, communication experiments face a specific recruitment challenge given that they involve two or more participants: scheduling and coordinating between multiple participants to join the experiment at the same time can be difficult, and if a single participant does not show up or drops out during the task, the whole session is at risk. One way to handle this issue is to send multiple confirmation and reminder emails and/or call participants directly prior to the experiment (in case of in-house testing), as well as having a backup participant at every time slot who is willing to participate on short notice in case of a last-minute cancellation. Given these constraints, data collection for communication experiments (especially those involving groups) can take longer than for regular experiments. Moreover, if the experiment is held face-to-face, it often requires the presence of an experimenter in the room to closely monitor participants' behaviour and ensure they are following the instructions and not using other means to communicate.

One possible way of overcoming these challenges is to turn to online experiments. The main advantage of an online setup is the ability to recruit many more participants from various locations, and test them

simultaneously without the need to bring them physically to the lab. The availability of individuals may be higher when tested from home, the chances of no-shows may be reduced, and the testing costs may be relieved. Specialized setups like a custom smartphone application (Morin et al. 2018) can even open up unique advantages such as free partner choice or testing larger groups of participants, which would not be feasible in
p. 54 the lab. However, online communication ↳ experiments also introduce novel challenges. For example, participants tested remotely may be engaged in other activities during the experiment, which may affect their performance, and may be more likely to drop out during the experiment. Moreover, online experiments are less naturalistic, as they do not include actual face-to-face interaction, and time-sensitive interactions between participants might get distorted by lag.

Arguably the largest methodological challenge for experimental semiotics is that participants' prior knowledge may affect the results of communication experiments: since participants are already fluent in one or more languages before starting the experiment, this might change their behaviour. For example, participants' linguistic experience may affect the phonology or morphosyntax of a specific emerging communication system, for instance, by producing vocalizations that follow the phonotactic rules of their native language, or by favouring the word order of their native language. Similarly, Müller et al. (2021) showed that the semantic structure participants created for colour terms in an artificial language closely resembled the one employed by their language community of English, German, or French. The specific biases introduced by participants' native language are hard to assess, yet could potentially be tested by comparing the communication systems created by participants from diverse linguistic backgrounds (see Żywiczyński et al. 2021). More crucial, however, is the concern that participants' rich prior linguistic knowledge is driving the general patterns observed in communication studies, such as the emergence of grammar or alignment on shared signals. If participants are relying heavily on their prior linguistic and semiotic knowledge, it may imply that rather than helping us understand the processes and mechanisms that are *responsible* for the evolution of language, what we see in communication experiments may simply be the *result* of such processes. These points are serious concerns which could be addressed (but not entirely solved) in several ways.

First, when designing signal and meaning spaces, it is important to avoid straightforward relations to established conventions in participants' known language(s), which they would be able to rely on. This problem is, however, not limited only to languages, but can arise from any prior shared association that participants can exploit, e.g. due to other cultural knowledge (e.g. describing an inverted-triangle shape as 'red' because of the traffic sign), or unintended iconic affordances (e.g. describing abstract diagonal lines as 'green' because they resemble a tree; of course, iconicity can be the entire point, like in many studies using gestures or free drawing). Regardless of the experimental parameters, trying to make sure participants are not acquainted with each other is also important (e.g. by inviting them separately), since they might be able to build on their past shared experience. As such, during the recruitment process, it is wise to avoid recruiting participants who are already familiar with one another, and to ensure that participants do not meet before the task.

Second, extending existing findings to child participants (who have far less extensive and explicit linguistic knowledge) is an important step in validating and replicating the patterns obtained by communication experiments with adults. However, the vast majority of the literature has focused on communication
p. 55 experiments with adult participants only, with only a handful of studies using child-friendly paradigms ↳ to examine communication patterns in child–child and/or in child–adult dyads (Anderson et al. 1991, 1994; Garrod and Clark 1993; Bohn et al. 2019; Kempe et al. 2019; Lister et al. 2021). The scarcity of communication experiments with children is likely due to children's generally poorer performance in artificial language paradigms (e.g. Ferman and Karni 2010; Raviv and Arnon 2018), and their poorer communicative skills (e.g. Anderson et al. 1991, 1994; Garrod and Clark 1993).

Nevertheless, a handful of studies did look at child communicators, and these can provide valuable insights into the potential similarities and differences between children and adults in terms of their potential role (or lack thereof) in the evolution of language. This is of particular interest given work on emerging sign languages

(Senghas and Coppola 2001; Senghas et al. 2004) and creoles (e.g. Bickerton 1984), which suggests that children have a special role in creating core properties of language by introducing structural innovations to novel communication systems. For example, Bohn et al. (2019) and Lister et al. (2021) showed that 6-year-olds are able to spontaneously create novel gestural signs in a communicative setup in a similar way to adults, but that their performance and ability to create compositional structure increased with age. Varying participants' age could also reveal how it may affect the emergence of conventionalized signals and/or grammar. Notably, the few communication studies conducted with children provide only weak support for children's roles as agents of language evolution, and suggest that adults are the ones scaffolding the process of conventionalization and the emergence of compositionality (e.g. Newman-Norlund et al. 2009; Kempe et al. 2019).

3.4 Conclusions

In this chapter, we have outlined some of the most important methodological aspects of communication experiments in the service of language evolution research, and demonstrated how this method can be used to tackle different questions related to the emergence of communicative conventions and grammatical structure. Notably, similar paradigms can be employed with artificial agents (Chapter 17, this volume), and communication experiments can fruitfully combine with other paradigms such as iterated learning (Chapter 1, this volume) to generate novel insights into the evolution of language.

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