Pointing prevents the emergence of symbolic referential signals: empirical tests in a common task framework

Kateryna Krykoniuk*[1], Fiona M. Jordan[2] and Seán G. Roberts[3]

*Corresponding Author: k.krykoniuk@sheffield.ac.uk
[1]Department of Russian and Slavonic Studies, University of Sheffield, Sheffield, UK
[2]Anthropology and Archaeology, University of Bristol, Bristol, UK
[3]School of English, Communication and Philosophy, Cardiff University, Cardiff, UK

Two experiments tested the conditions under which symbolic referential communication systems emerge. Naive participants were placed in an 'arena' with conditions that were predicted to motivate the emergence of a symbolic system. However, this failed to occur in an arena based on collaborative building under several conditions due to the effectiveness of pointing. In contrast, an arena based on maintaining a fire provided a need to communicate distal meanings and led to greater likelihood of symbol system emergence. We present a tentative causal model that explains the results and suggests future studies.

1. Introduction

Pointing has been invoked as an important tool in the development of symbolic referential signals (SRS): a system of shared, symbolic signals that refer to objects in the world. Pointing can help ground the meaning of a signal by establishing joint attention between two interlocutors on a referent (e.g. Steels & Belpeame, 2005). However, pointing is also a powerful communication tool in its own right. This study investigates what specific ecological or social conditions are required for a symbolic system to be effective over and above pointing. Borrowing from Hurford, we call these conditions the 'arena of language evolution' (Hurford, 1989; 1990). Roberts, Irvine & Jordan (2022) suggested that this can be investigated using a 'common task framework': a series of comparable practical simulations that forces researchers to specify their principles and test them against each other in controlled conditions. That is, a sound theory should be able to define an 'arena' including an environment, and a task for agents to complete that reflects relevant and plausible analogues of early hominid life. The agents should start exhibiting the predicted communicative behaviour under the right arena conditions. Previous studies found that, contrary to some theoretical predictions, SRS were unlikely to emerge in an arena where agents had to collaboratively build a structure out of coloured blocks (Irvine & Roberts, 2016). While participants had the ability to invent a symbolic convention to refer to different block types, they simply used pointing with trial-and-error. The suggestion was that the cost of setting up a symbolic system was too high in comparison to the effectiveness of pointing. However, perhaps the critical barrier was not pointing *per se*, but the low cost of the trial-and-error strategy. Another possibility is that the system of meanings was too simple to require a dedicated symbolic system. In section 2, we replicate and extend the previous experiment to test these possibilities by increasing the cost of destroying blocks (reducing the effectiveness of trial-and-error) and by increasing the number of block colours. In contrast, section 3 presents a new arena based on theories of fire maintenance.

2. Arena A: Building (or collaborative manipulation of objects)

Replicating Irvine et al. (2016), the following arena was set up in *Minecraft*:
Environment: A flat field with markers showing the outline of a building.
Task: Two participants needed to follow a plan to build an abstract building from coloured blocks. Participants were not allowed to speak, but they could knock on the table or 'gesture' via their avatar's movements in the game. Participants were given up to 20 minutes to complete the task.
Asymmetry of information: Each participant had half of the plan of the building. The plan was asymmetric and unsystematic, meaning that participants had to communicate to each other the location and colours of blocks.
Division of labour: The plan included 4 colours of blocks, but each participant was only able to place two colours. This is analogous to individuals being specialised in the use of specific building materials. Participants were allowed to destroy blocks of any colour. There were two additional conditions. The second condition is identical, except blocks took twice as much time to destroy. The third condition included 8 colours of blocks (4 unique colours each) instead of 4.
33 pairs participated (11 in each condition, a given participant only took part in one condition). The experiment was recorded and then participants filled out a questionnaire about their communication strategy, then they were informally interviewed. The videos, interviews and participant questionnaires were analysed for various categories of communication strategies. A pair was considered to have established an SRS if both participants' questionnaires reported the same communicative convention for identifying the colour of their blocks, or if the interview revealed such a system. The form of the signal could be anything (knocking, jumping, spinning etc.). Other strategies were identified from the data rather than being assumed *a-priori*, and are described below.

2.1. Results

Every pair of participants succeeded in establishing a strategy to solve the task. The typical procedure was that each participant would start by building some portion of their own side of the building. Then, they would realise that they needed the help of their partner and seek their attention. Pairs built one side at a time, so one participant would take the role of 'director', indicating locations and colours, and the other taking the role of the 'builder' who placed the blocks.

Table 1 shows the communication strategies that emerged in each condition. Note that these are not mutually exclusive. In the building situation, the predominant strategy was to use pointing to identify locations and trial and error to identify block colour: a director would indicate a place for the builder to place a block, but destroy it if it was the wrong type. To assist this strategy, the majority of all pairs established conventions for signaling 'correct' or 'incorrect', most often analogies of the real-world convention of nodding and shaking the head. While this is a symbolic convention, it does not refer to objects in the game world. Therefore, we did not take this as evidence for the emergence of symbolic referential signals.

Beyond trial and error, the dominant secondary strategy varied by condition. Two strategies used a feature of *Minecraft* where players can see the colour of the blocks their partners are currently holding. In the initial condition (4 colours), the most frequent secondary strategy was for the director to switch the blocks they themselves were holding. This was a cue for the builder to change the block type they were holding. While this relies on an analogy, the signal's meaning is "change your block" or just "incorrect". It was highly contextual and could not be used to refer to a specific colour in a different context. That is, it is an extension of the 'trial and error' system that avoids needing to place and destroy a block.

Table 1. Strategies adopted in each condition of the building arena (dominant strategy in bold).

Condition	*Correct/ Incorrect*	*Director switches blocks*	*Builder switches blocks*	*Indexical system*	*SRS*
4 colours	91%	**55%**	27%	18%	9%
Hard blocks	73%	9%	**45%**	9%	9%
8 colours	82%	18%	27%	**64%**	9%

In the 'hard blocks' condition, the dominant strategy shifted to a similar system, but this time the builder would choose a block type and wait for confirmation from the director that it was the right colour (e.g. by nodding). This is essentially the same as pointing at a candidate object, and is a logical strategy to adopt when placing the wrong block colour is a more costly mistake.

In the 8 colour condition, the dominant strategy was an indexical. Participants pointed to existing blocks to indicate the colour or placed a set of 'reference blocks' to one side of the main building to have access to a full set of colours. This strategy relies on pointing alone. It is more efficient than trial and error with the expanded number of colours, though directors sometimes spent time encouraging builders to place reference blocks in order to point at them.

In general, the condition affected the dominant strategy that emerged (Fisher's exact test of director/builder/indexical strategy frequency, $p = 0.038$), indicating that the task demands were sufficiently different to motivate different communication strategies. However, only one pair in each condition established an SRS. In one case in the 4 blocks condition, the pair established a system immediately before doing anything else. One participant knocked once holding a blue block, knocked twice holding a red block, then knocked once holding a blue block. This redundant repetition signalled an ostensive action. Their partner understood the idea and did the same with their blocks. This process took only 17 seconds and was the strategy expected in the previous study. So, while establishing a symbolic communication system is clearly possible, the arena does not provide enough motivation for this to emerge frequently. Indeed, in many cases, participants reported that they had considered establishing a system, but decided that it was not worth the effort. In one condition, the pairs even managed to complete much of the task without communicating directly: one participant placed blocks randomly and the other destroyed incorrectly placed blocks. In summary, in the building arena, the ability to point at objects makes an SRS redundant. This suggests that an arena that motivates the emergence of an SRS needs to involve meanings that cannot be pointed to.

3. Arena B: Fire maintenance

There are many possible arenas with distal meanings. However, given the preference for pointing solutions, symbolic referential signals may only emerge when the arena discourages pointing strategies. Since participants are free to move around the world, there are few realistic scenarios where individuals can be prevented from going together to the referents. Put another way, if you can point at something to request someone to give it to you, you can just pick it up yourself. So the key property is that the most efficient solution should involve the 'director' needing to be distant from the referents at the point when they are requesting them. That is, the 'distal' property of meanings is not necessarily inherent to the meaning or referent, but emerges from an interaction between where the referents and interlocutors are in context. Fire maintenance may provide inspiration for such an arena (Twomey, 2013). Since fire use preceded fire making, fires from natural sources would need to be constantly monitored and maintained. However, fuel would also need to be gathered. This inspired an arena where participants had to collect raw materials and 'smelt' them into refined materials:

Environment: A narrow strip of land between a lake and a sheer mountain. A furnace was placed at one end near a source of fuel, and a 'mine' was placed at the other end with a source of gold ore and green ore. In an alternative condition, the mine was placed near to the furnace.

Task: Smelt the ores into 'ingots' by adding ore and fuel to the furnace.

Asymmetry of information: The 'smelter' had a set of cards that indicated the order in which ingots should be produced. This was not observable to the 'miner'.

Division of labour: The smelter was taught to use the furnace and the miner was taught to obtain ore from the mine, though there was no rule against swapping.

The rest of the methods were identical to arena A. The expected optimal strategy was for the smelter to communicate the type of ore required to the miner, then the miner gets the ore while the smelter gets fuel, monitors the furnace, and produces the ingots when the miner returns. The arena was designed so that the time it took to get ore was roughly equal to the time to 'maintain' the furnace and produce an ingot. This meant that, if the participants were acting efficiently, the smelter would remain at the furnace and both participants would not be in the same place with both types of ore, avoiding an opportunity for pointing at a required object. The analogue in the real world might be needing to tell someone to collect a specific type of fuel while they kept a fire going.

3.1 Results

Table 2 shows the frequency of established SRS for both arenas. The fire arena motivated 36% of the pairs to establish an SRS, marginally more frequently than the building arena (Fisher's $p = 0.053$). More tellingly, at least one participant in each pair attempted to establish an SRS in 86% of trials, compared with only 12% of trials in the building arena ($p = 0.0001$). Only two fire trials did not attempt to establish a symbolic system, and in one of them a smelter reported that they would have done but thought that they were not allowed to go to the mine. In fact, we had to exclude one trial from the data because a participant shouted out a symbolic referential strategy to their partner before the experimenter had finished announcing the rules of the task. In contrast, when the mine was near, attempted SRS were significantly rarer ($p = 0.002$) and similar to the Building arena.

Table 2. The frequency of established and attempted SRS in each arena.

Arena	*Established SRS*	*Attempted SRS*
Building	9%	12%
Fire Maintenance (distant mine)	36%	82%
Fire Maintenance (near mine)	9%	9%

The symbolic system was usually established by both participants going to the mine, pointing to a type of ore and producing a signal with a knock. That is, pointing was important to help ground the signals, but the necessity of signals was created by the conditions of the arena.

4. Discussion

The building arena consistently failed to motivate a symbolic referential communication system. Instead, participants found creative solutions involving pointing. Manipulating the opportunity cost and the number of meanings changed the secondary communication strategy, but did not affect the likelihood of referential symbols emerging. In contrast, SRS frequently emerged in the fire arena, and participants were more likely to report feeling a need for such a system. A tentative causal model is suggested in figure 1: Conditions of the arena create pressures for specific types of social interaction, and these change the effectiveness of various communication strategies. The core of the model is that asymmetry of information and division of labour create a need for communication, and this increases the effectiveness of a pointing or symbol system and the likelihood of one emerging. Asymmetry of information was provided by dividing the building plan in the building arena and by specialised training and only the smelter knowing the ore sequence in the fire arena. Division of labour was motivated by having specialised blocks in the building arena but was more complex in the fire arena: specialized training, a need to monitor the fire, and a distant mine. The effectiveness of an SRS is affected by the need for communication, how much time the symbol system costs to set up, and how effective a pointing strategy is. If pointing can solve the task, this directly prevents the need for a symbol system and indirectly increases the opportunity cost of setting one up. Increasing the number of blocks was predicted to reduce the effectiveness of trial-and-error, but it also increased the cost of setting up a symbol system. Increasing the hardness of blocks was predicted to increase the cost of mistakes, so reduce the relative cost of setting up a symbol system since both pointing and symbols would provide more confidence. However, apparently it did not reduce the relative effectiveness of the pointing system enough for a symbolic system to emerge. In contrast, the fire arena created distal meanings: the most efficient task solution involved the smelter needing to request an item when it was not immediately present. This reduced the effectiveness of pointing, reducing the relative cost of setting up a symbol system (compared to both participants travelling to the mine) and motivated participants to invent an SRS.

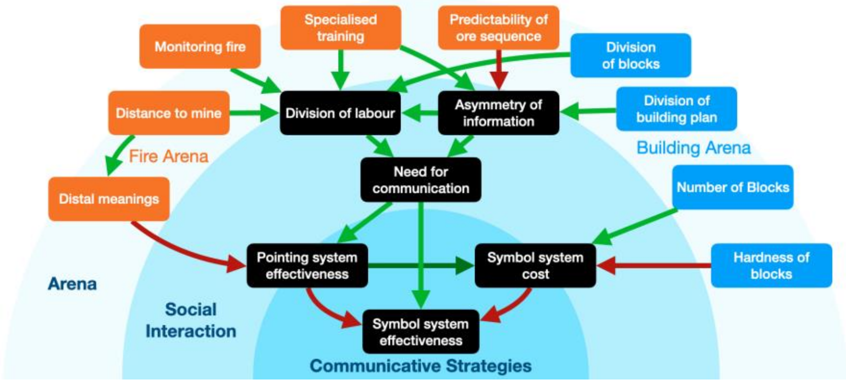

Figure 1. A causal model of symbol system emergence. Green: positive effect, red: negative effect.

There may be many other arenas that motivate the evolution of symbols, including negotiating the division of labour, teaching, or the need to refer to meanings that distant in time. The common task framework can also test and contrast these.

Acknowledgements

KK and SGR were supported by an AHRC grant AH/T006927/1.

References

Hurford, J. R. (1989). Biological evolution of the Saussurean sign as a component of the language acquisition device. *Lingua*, *77*(2), 187-222.

Hurford, J. R. (1990). Nativist and functional explanations in language acquisition. *Logical issues in language acquisition*, *85*, 136.

Irvine E. and Roberts S. (2016). Deictic Tools Can Limit The Emergence Of Referential Symbol Systems. In S.G. Roberts, C. Cuskley, L. McCrohon, L. Barceló-Coblijn, O. Fehér & T. Verhoef (eds.) The Evolution of Language: Proceedings of the 11th International Conference (EVOLANG11). Available online: http://evolang.org/neworleans/papers/99.html

Roberts, S. (2018). What are the social, economic and ecological conditions for the evolution of complex communication systems? Comment on "Rethinking foundations of language from a multidisciplinary perspective" by T. Gong et al. *Physics of Life Reviews* 26 (152-154).

Roberts, S., Irvine, E. & Jordan, F. (2022). The Common Task Framework: Using Causal Theories From Linguistic Anthropology to Explore the Emergence of Symbolic Communication. In Ravignani, A., Asano, R., Valente, D., Ferretti, F., Hartmann, S., Hayashi, M., Jadoul, Y., Martins, M., Oseki, Y., Rodrigues, E. D., Vasileva, O. & Wacewicz, S. (Eds.): Proceedings of the Joint Conference on Language Evolution (JCoLE). doi:10.17617/2.3398549.

Steels, L., & Belpaeme, T. (2005). Coordinating perceptually grounded categories through language: A case study for colour. *Behavioral and brain sciences*, *28*(4), 469-488.

Twomey, T. (2013). The cognitive implications of controlled fire use by early humans. *Cambridge Archaeological Journal*, *23*(1), 113-128.