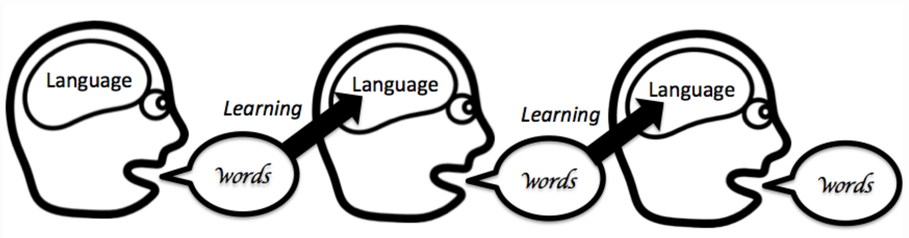
Language evolution in the lab

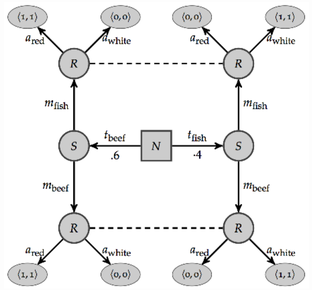
language evolution synthesized

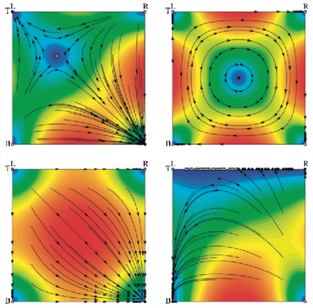
agent-based simulations

iterated learning

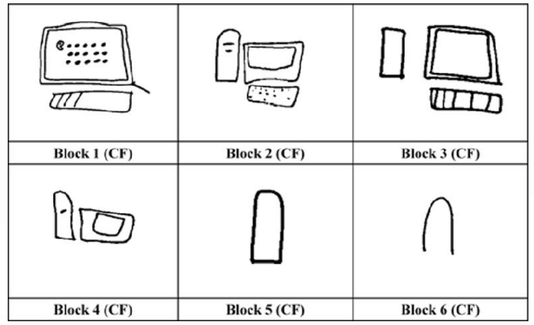


evolutionary game theory





experimental semiotics



evolving an artificial code

Bruno **Galantucci** (2005) An Experimental Study on the Emergence of Human Communication Systems. **Cognitive Science** 29 737—767

SETUP

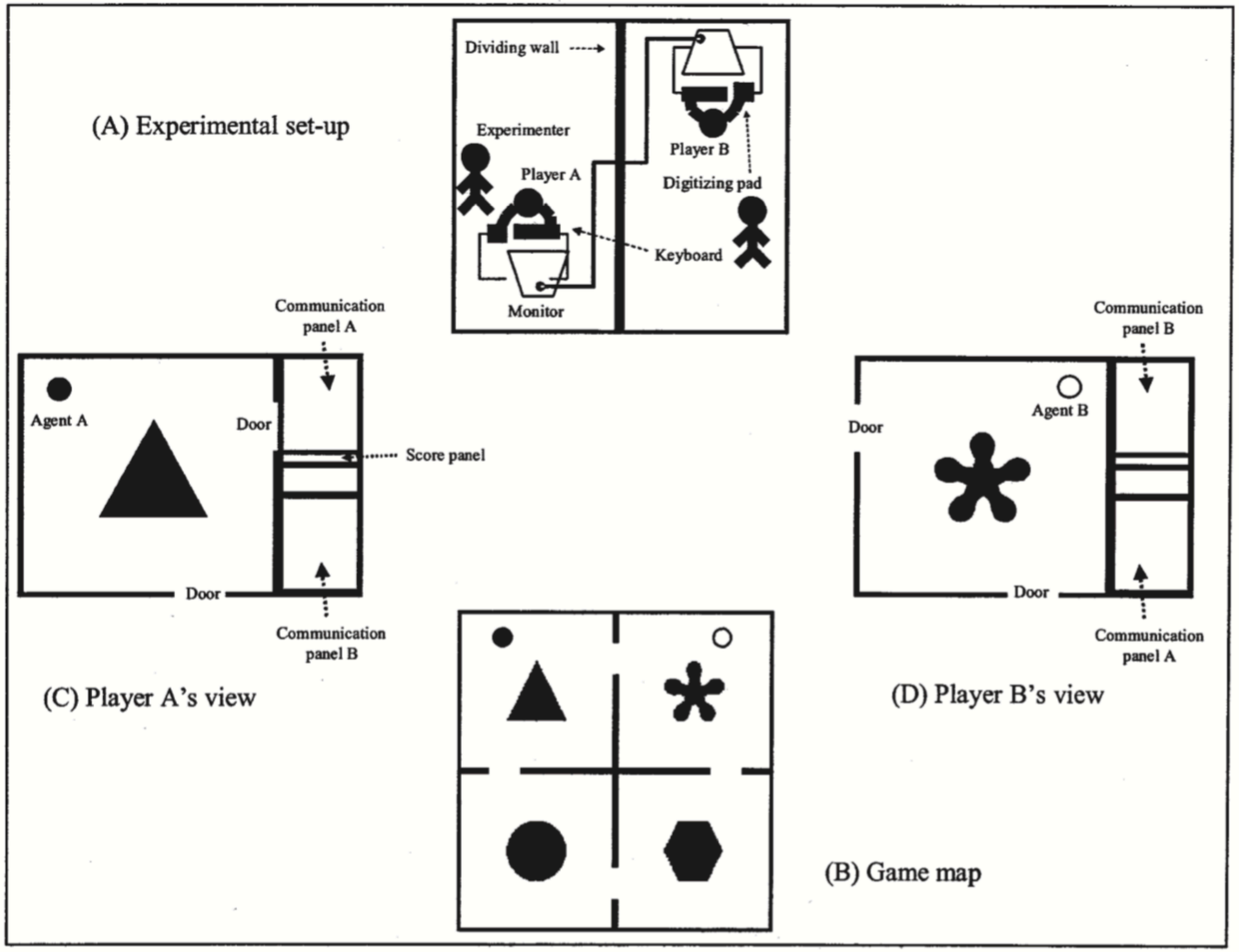


Fig. 1. Overview of the basics of the game. (A) Experimental setup. (B) Game 1 map. (C) Player A's view of the map. (D) Player B's view of the map.

SETUP

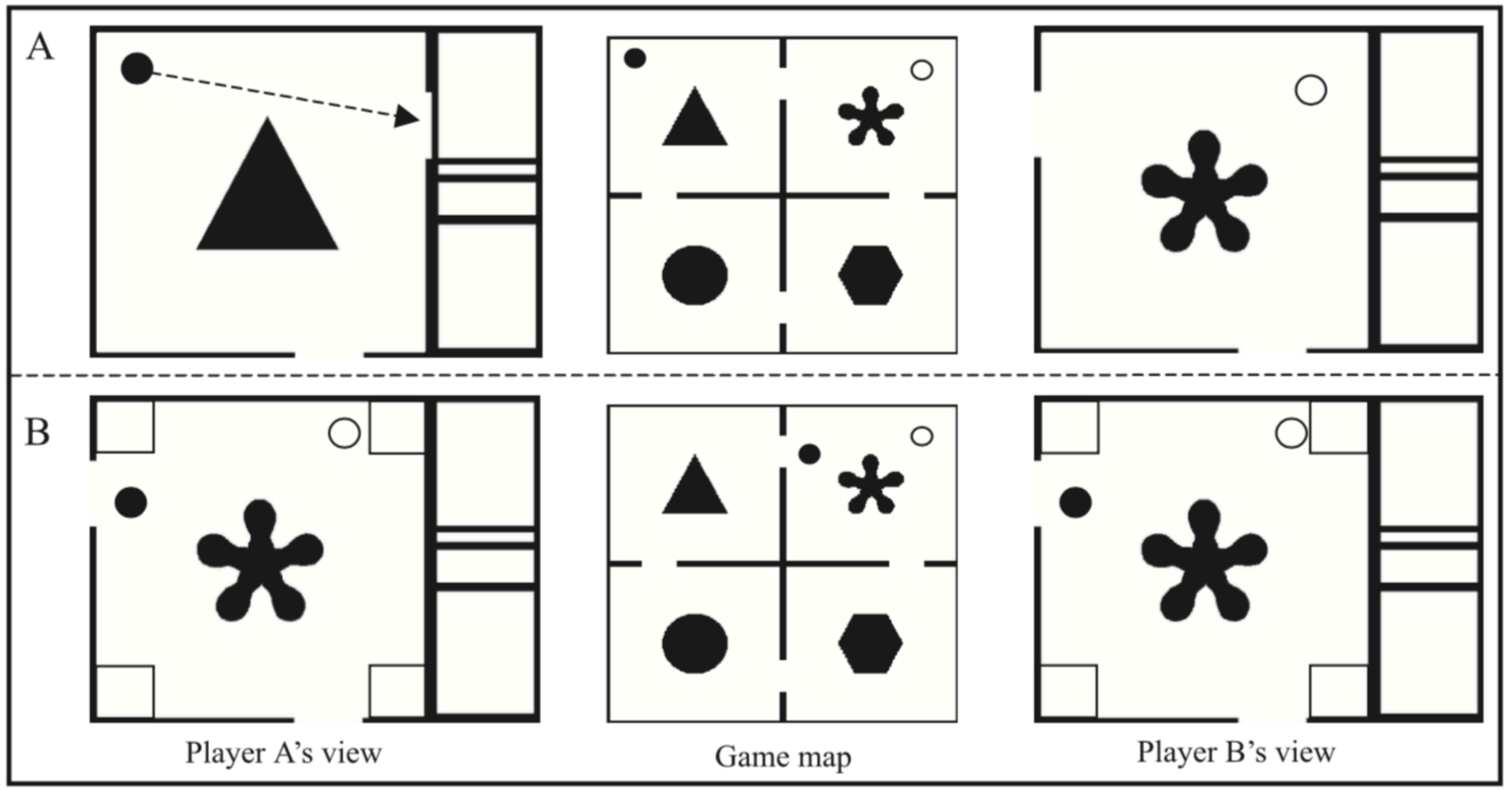


Fig. 2. A move in the game. (A) Agents are in different rooms. Player A's agent (black dot) moves rightward from the triangle room. (B) Player A's agent has passed through the doorway and found Player B's agent (white dot) in the adjacent room. Notice that, when in the same room, players see the same display.

SETUP

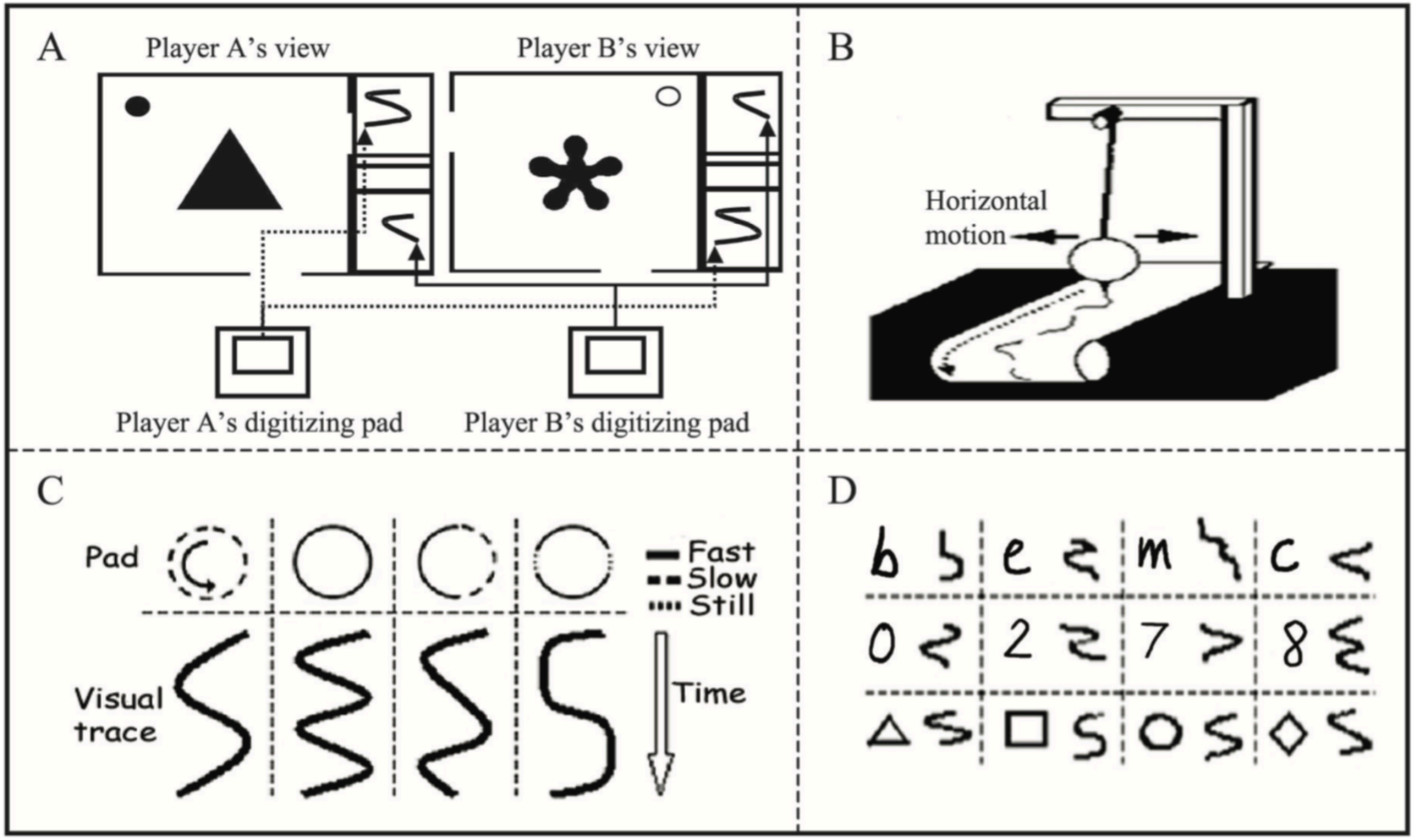
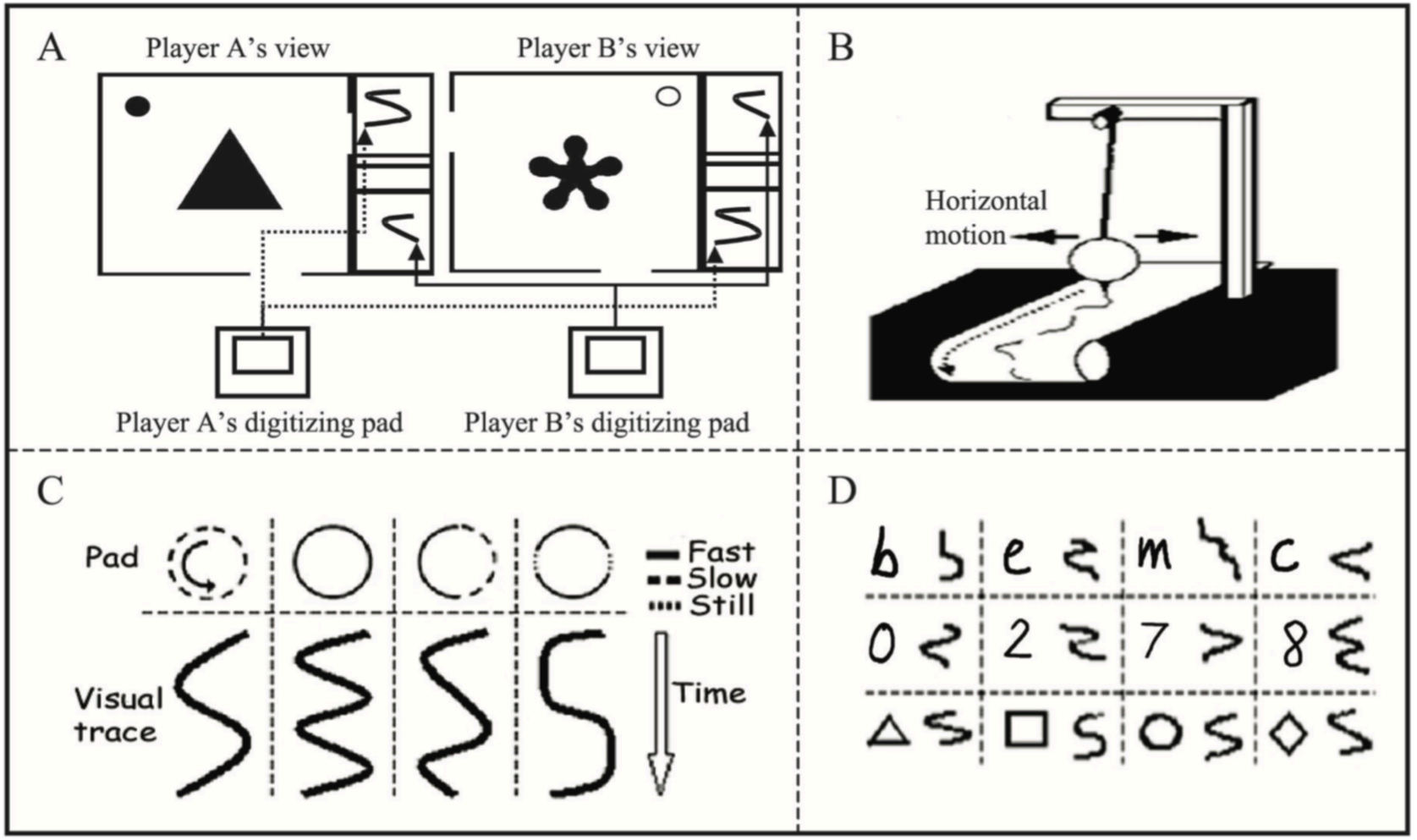


Fig. 3. The communication medium. (A) The signal generated by players' digitizing pads is relayed to both players' communication panels. (B) The signal has the properties of a quickly fading intermittent time series such as the signal generated by a seismograph that allows discontinuities. (C) The visual outcome of the same geometric shape depends on the velocity profile of the drawing movement. (D) How the drawings of familiar letters, numerals, and shapes appear on the communication panel.

SETUP



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PROCEDURE

- participants: 10 pairs of participants; paid 8$/h
- successful trial: get both participants into the same room with maximally one room change of each player
- scoring: players start with a score of 50; each minute 1 point is deduced (no matter what); each failure deduces 4 points; each success gains 2 points;
- goal: reach 100 points
- communication: free to use any time
- final test: assess the communication system (if any) player had evolved

RESULTS

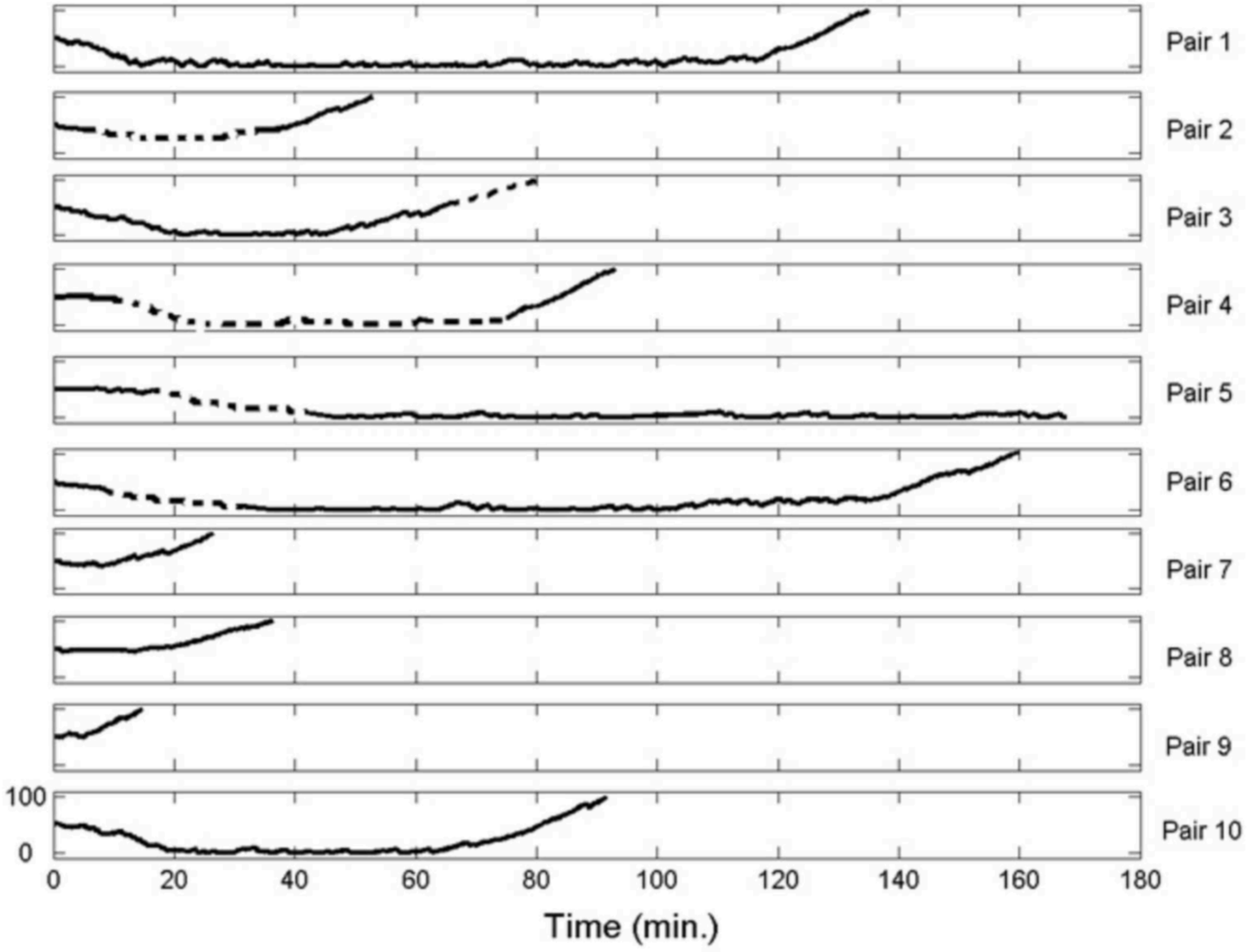


Fig. 4. Score plots for Study 1A. The ticks on the axes for Pairs 1 to 9 have the same values as the ticks on the axes for Pair 10, namely 0 to 100 points on the ordinate and 0 to 180 min on the abscissa. (The dashed portions of the lines for Pairs 2–6 signal that the lines are not plotted on the basis of the history files the computer generated for the game, but have been reconstructed on the basis of the experimenters' notes. The reconstruction became necessary because of computer failures.)

RESULTS

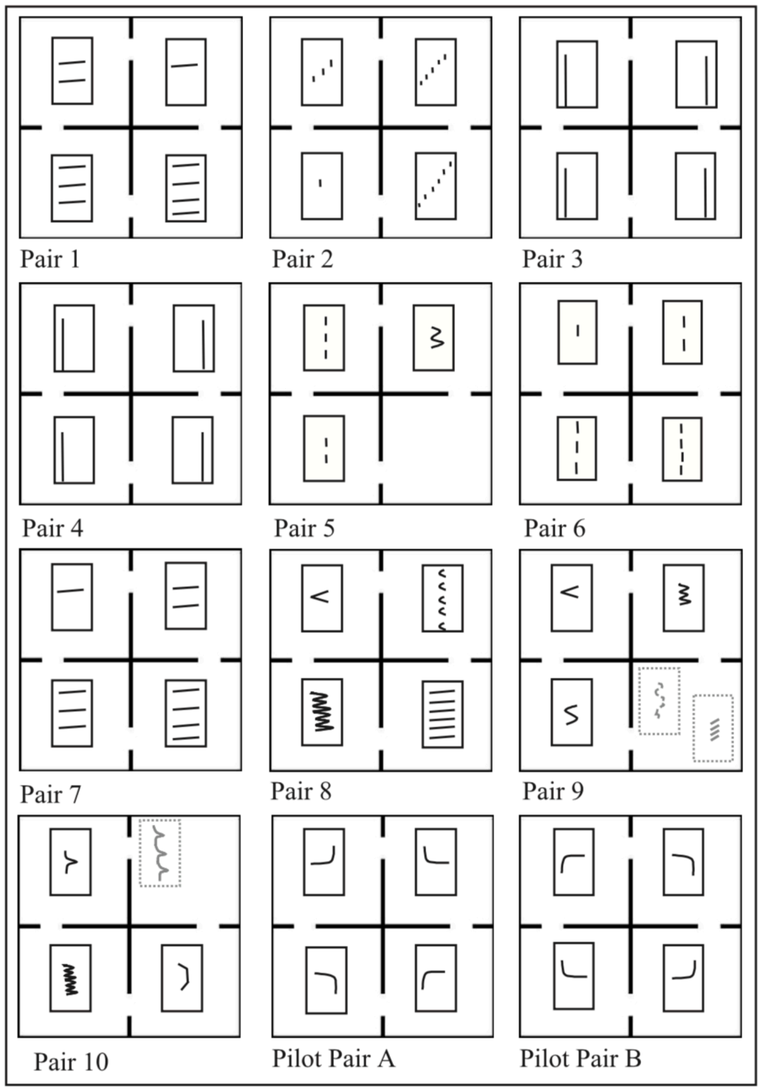
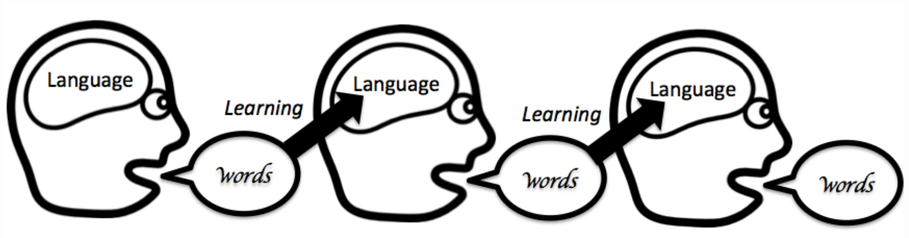


Fig. 5. Pairs' sign systems for Game 1. The signs are presented in the room they stand for. The rectangles around the signs represent the communication panels within which the signs were drawn (Fig. 1). Dotted rectangles in gray indicate signs used only by one player in the pair. Two signs in the same room indicate that players did not use the same signs for that room. Pilot Pairs A and B participated in a pilot study conducted with Game 1 (Galantucci, Fowler, & Richardson, 2003).

iterated learning in the lab

Simon **Kirby**, Hannah **Cornish** and Kenny **Smith** (2008) *Cumulative cultural evolution in the laboratory: An experimental approach to the origins of structure in human language*. **PNAS** 105 (31) 10681—10686

iterated learning



SETUP EXPERIMENT 1

- participants: 40 participants arranged into 4 chains of 10 learners
- procedure: each participant gets random half of the language to be learned; then produces a string for each meaning (including for novel meanings not encountered during training)
  - initial participant tries to learn initial random language
  - every next participant tries to learn output from the previous

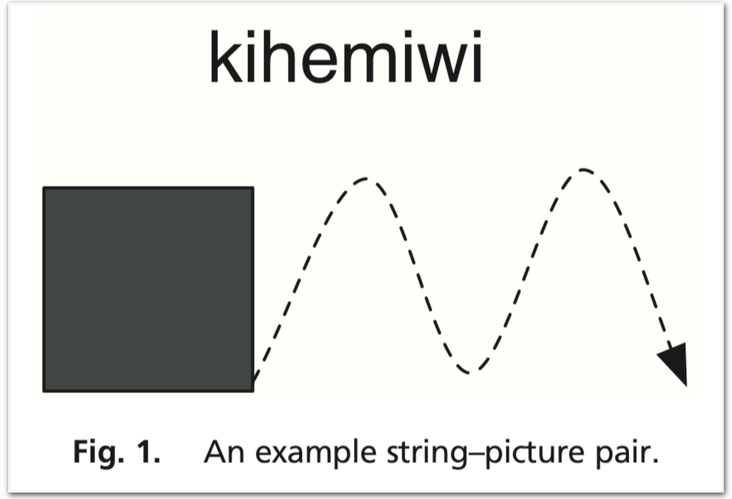


Fig. 1. An example string–picture pair.

MEASURES OF INTEREST

- error: rescaled average Levenshtein between produced word and correct word (including for meanings not in the training set)
- structure: correlation between edit-distances of words and edit-distance of corresponding meanings
  - edit-distances of meanings by form, movement and color

RESULTS EXPERIMENT 1

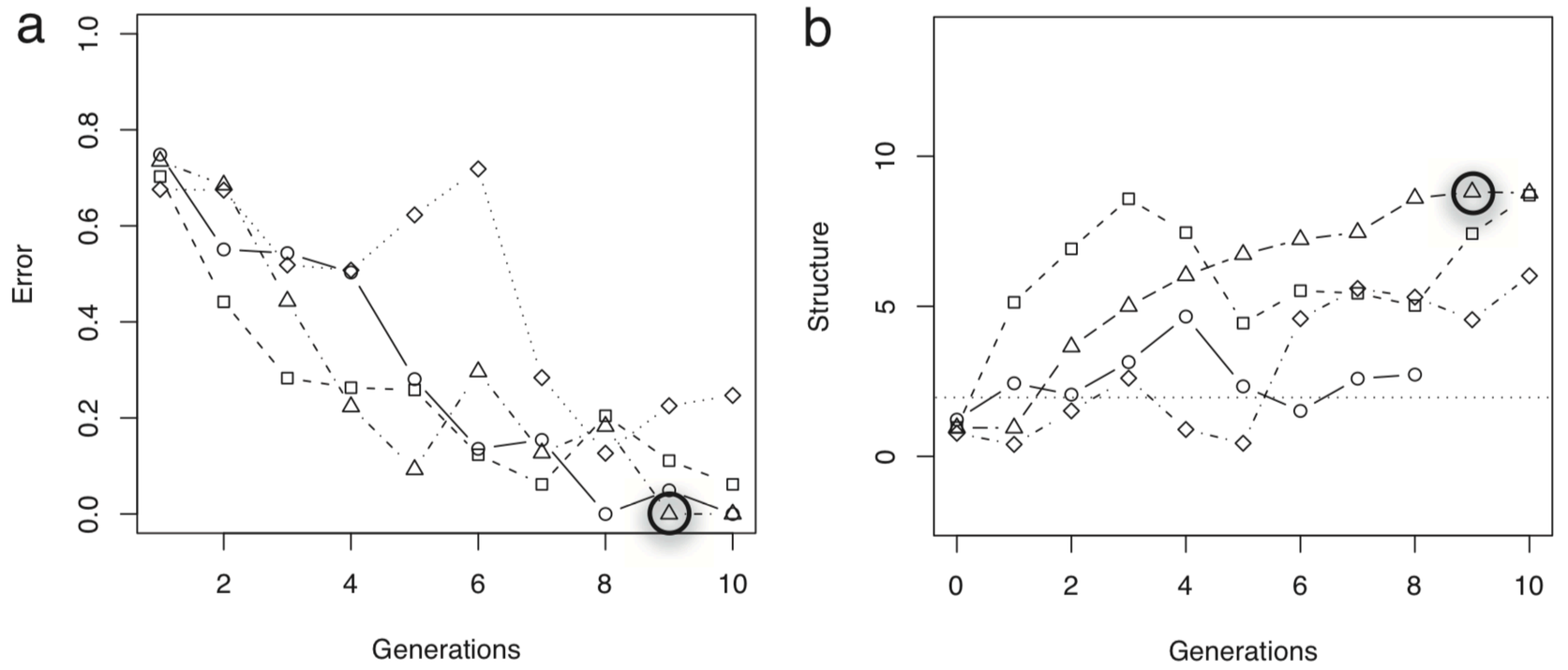


Fig. 2. Transmission error and a measure of structure by generation in 4 chains. *a* shows the increase in learnability (decrease in error) of languages over time. *b* shows structure in the languages increasing. The dotted line in *b* gives the 95% confidence interval so that any result above this line demonstrates that there is a nonrandom alignment of signals and meanings. In other words, structure in the set of signals reflects structure in the set of meanings. In 2 cases, this measure is not defined and therefore is not plotted (see *Methods*). The language discussed in the paper is circled.

RESULTS EXPERIMENT 1

Fig. 3. An example evolved language in the first experiment. This language exhibits systematic underspecification, enabling learners to reproduce the whole language from a fragment.

Table 1. Number of distinct words by generation in the first experiment

Generation	0	1	2	3	4	5	6	7	8	9	10
○ Chain 1	27	17	9	6	5	4	4	2	2	2	2
□ Chain 2	27	17	15	8	7	6	6	6	5	5	4
△ Chain 3	27	24	8	6	6	5	6	5	5	5	5
◇ Chain 4	27	23	9	10	9	11	7	5	5	4	4

SETUP EXPERIMENT 2

- participants: 40 participants arranged into 4 chains of 10 learners
- procedure: each participant gets random half of the language to be learned after **filtering for ambiguous word-meaning pairs**; then produces a string for each meaning (including for novel meanings not encountered during training)
  - initial participant tries to learn initial random language
  - every next participant tries to learn output from the previous

RESULTS EXPERIMENT 2

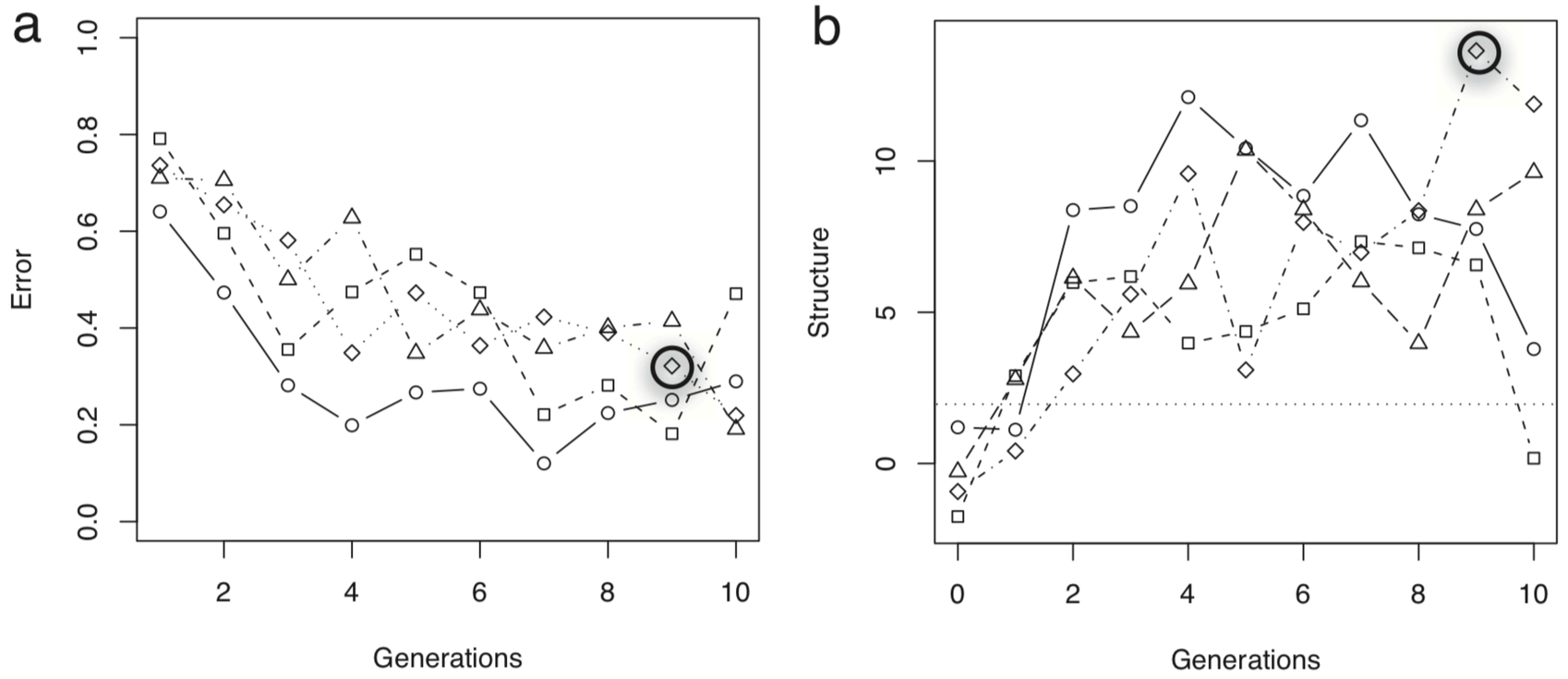


Fig. 4. Transmission error and structure by generation in the experiment in which ambiguous data were removed from the training set at each generation. *a* gives error for the whole language; *b* gives structure. These results show that, despite the blocking of underspecification, structure still evolves that enables the languages to become increasingly learnable. The language discussed in the paper is circled.

RESULTS EXPERIMENT 2

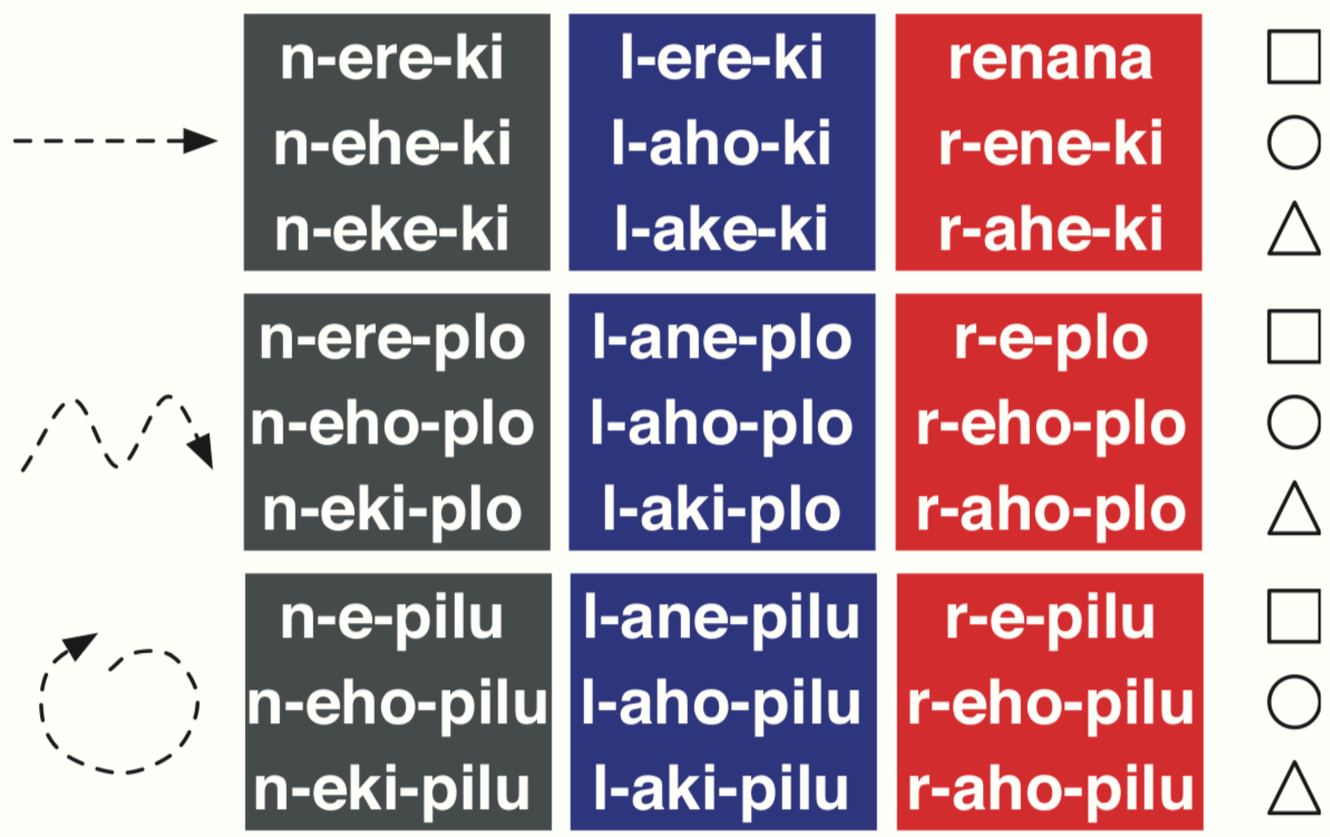


Fig. 5. An example evolved language in the second experiment. The language is structured: the string associated with a picture consists of substrings expressing color, shape, and motion, respectively. The hyphens represent 1 way of analyzing the substructure of these strings and are added purely for clarity; participants in the experiment always produced strings of characters without spaces or any other means of indicating substructure.

Table 2. Number of distinct words by generation in the second experiment

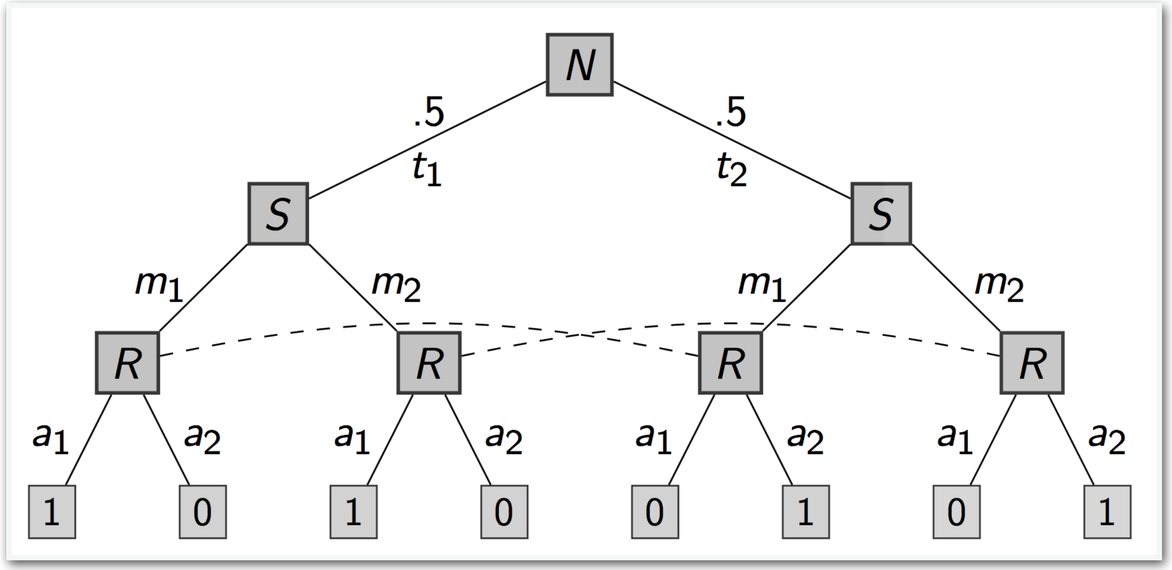
Generation	0	1	2	3	4	5	6	7	8	9	10
○ Chain 1	27	23	22	17	21	21	17	21	25	13	16
□ Chain 2	27	26	13	10	10	16	16	12	12	13	12
△ Chain 3	27	11	16	14	12	17	14	16	20	19	12
◇ Chain 4	27	19	19	17	19	17	22	23	21	27	23

signaling signalhood

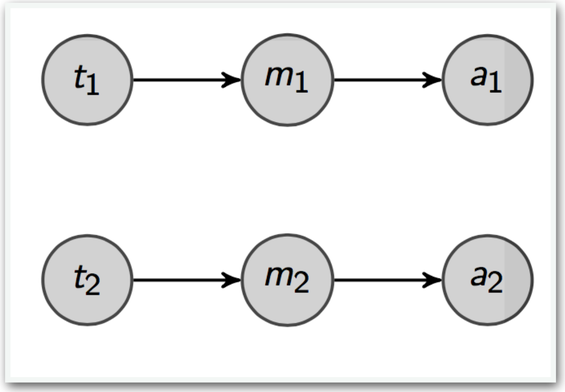
Thomas Scott-PhilippsSimon **Kirby**, Hannah **Cornish** and Kenny **Smith** (2009) *Signalling signalhood and the emergence of communication*. **Cognition** 113 226—233

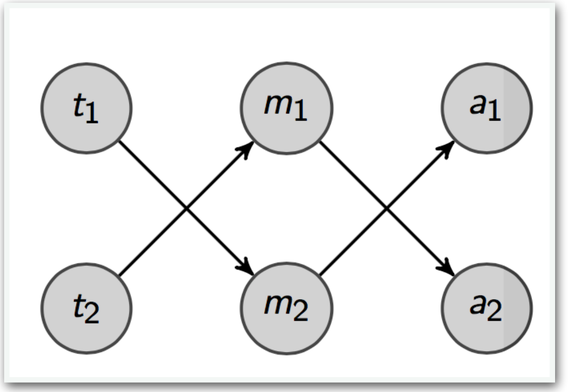
SIGNALING THEORY

SIGNALING GAME



EVOLUTIONARY STABLE STATES LEWIS





STRATEGIES

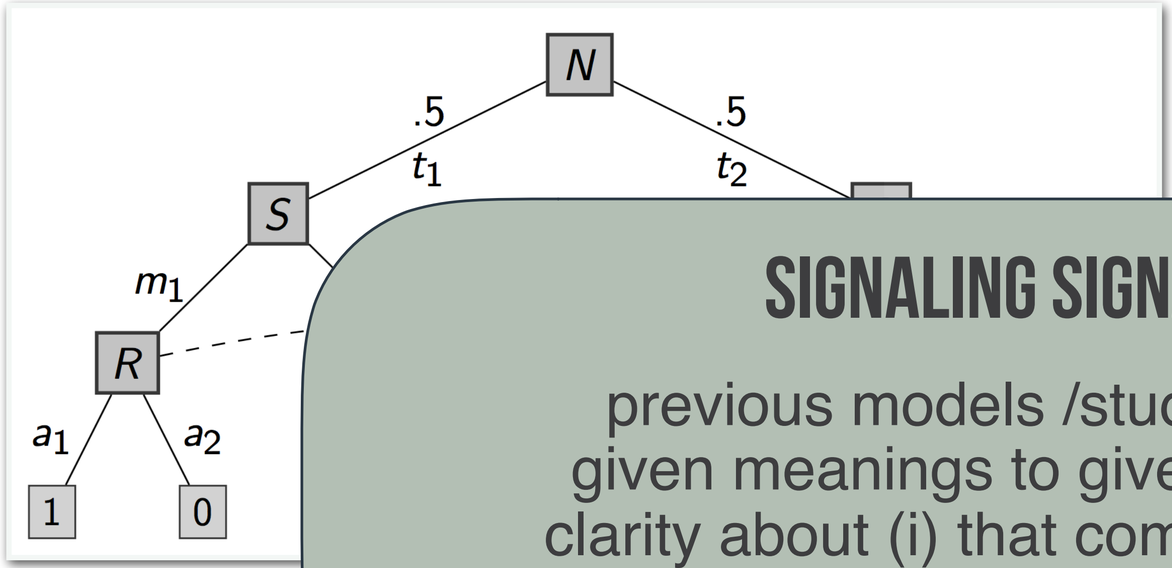
sender: $P_S(m \mid t)$ receiver: $P_R(a \mid m)$

INFORMATION CONTENT VECTOR SKYRMS

$$\text{ICV}(m) = \left\langle \log \frac{P_S(t_1 \mid m)}{P(t_1)}, \log \frac{P_S(t_2 \mid m)}{P(t_2)} \right\rangle$$

SIGNALING THEORY

SIGNALING GAME



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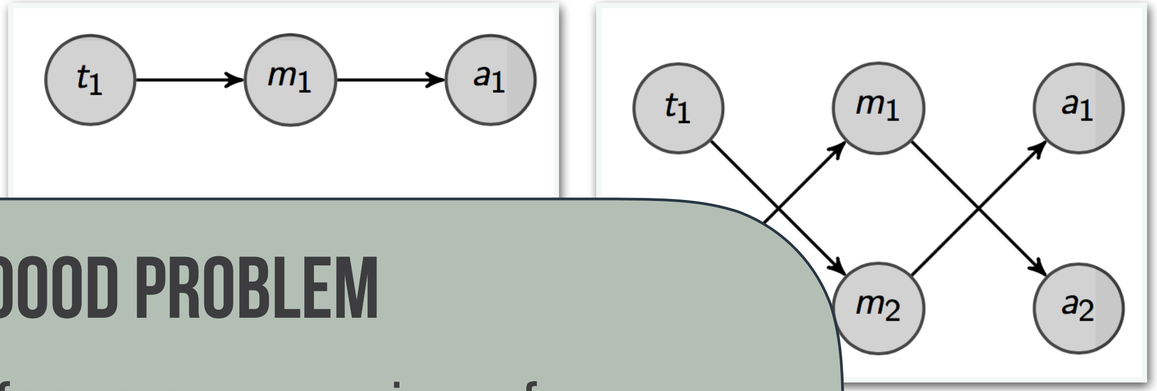


SIGNALING SIGNALHOOOD PROBLEM

previous models /studies focus on mapping of given meanings to given signals with reasonable clarity about (i) that communication needs to occur and (ii) what the communication channel is

STRATEGIES

sender: $P_S(m \mid t)$ receiver: $P_R(a \mid m)$

NT VECTOR SKYRMS

$$\text{ICV}(m) = \left\langle \log \frac{P_S(t_1 \mid m)}{P(t_1)}, \log \frac{P_S(t_2 \mid m)}{P(t_2)} \right\rangle$$

DESIGN

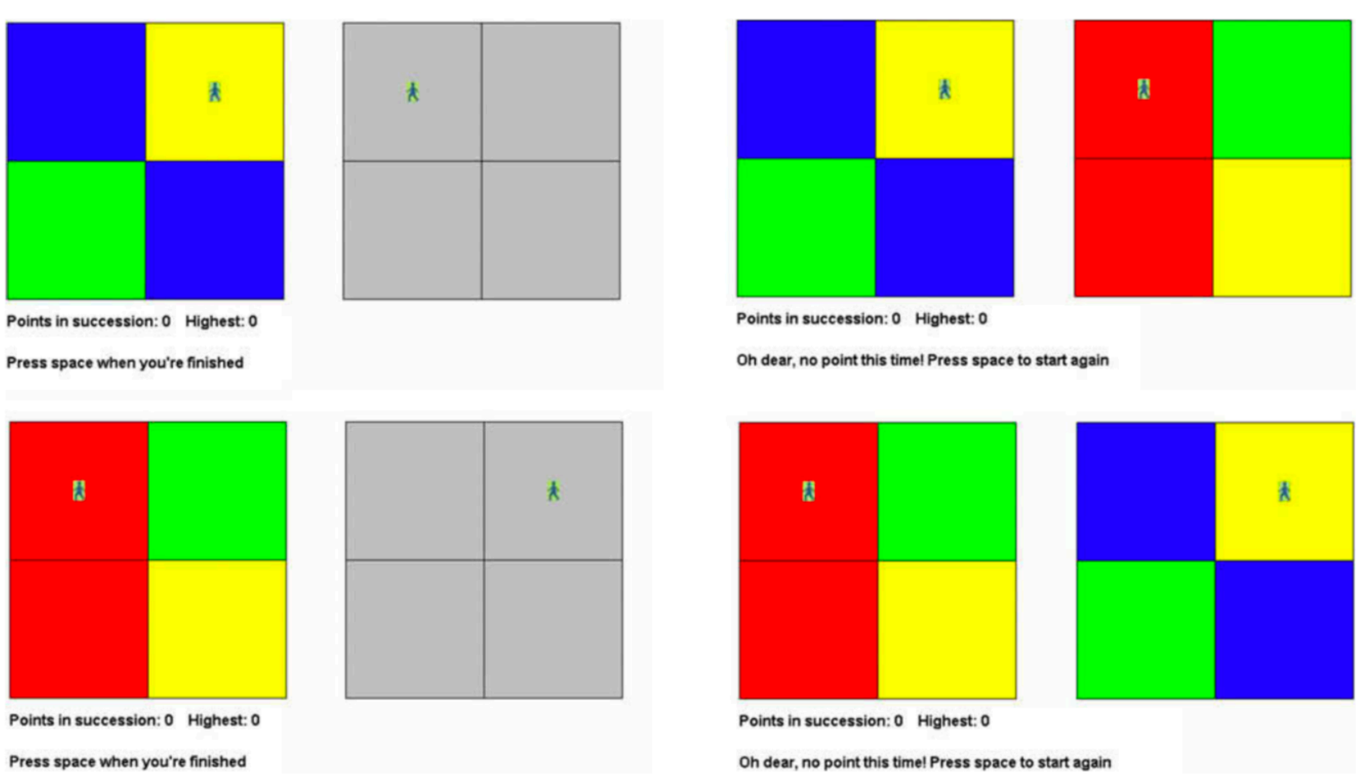


Fig. 1. Screen-shots of the game. Participants play multiple rounds of the game on networked computers. These screen-shots show the view of both players, one on each row, both before (left-hand side) and after (right-hand side) both participants have pressed space to finish their turn. Participants can see their own colours but not the other participants'. Participants move around their boxes at will, and their movements are fully visible to the other participant. At any time the participants may choose to press space to finish their turn, and when they do so all colours are revealed to both participants. Participants score a point if they finish on the same colour. Here, the participants have failed to score a point because they have finished the round on different coloured squares. After each round, the squares are reassigned colours randomly, although there will always be at least one shared colour (in this case, green). Succeeding at the game requires finding some way to communicate the intended destination colour each round. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

SETUP EXPERIMENT 1

- participants: 12 pairs of participants
- procedure: each pairs plays for 40 minutes uninterrupted (after a 3 min training phase); each agent moves around until they decide on a quadrant;
- trials: colors assigned to quadrants where random except that players must have at least one color in common
- points: longest streak of subsequent successes

RESULTS EXPERIMENT 1

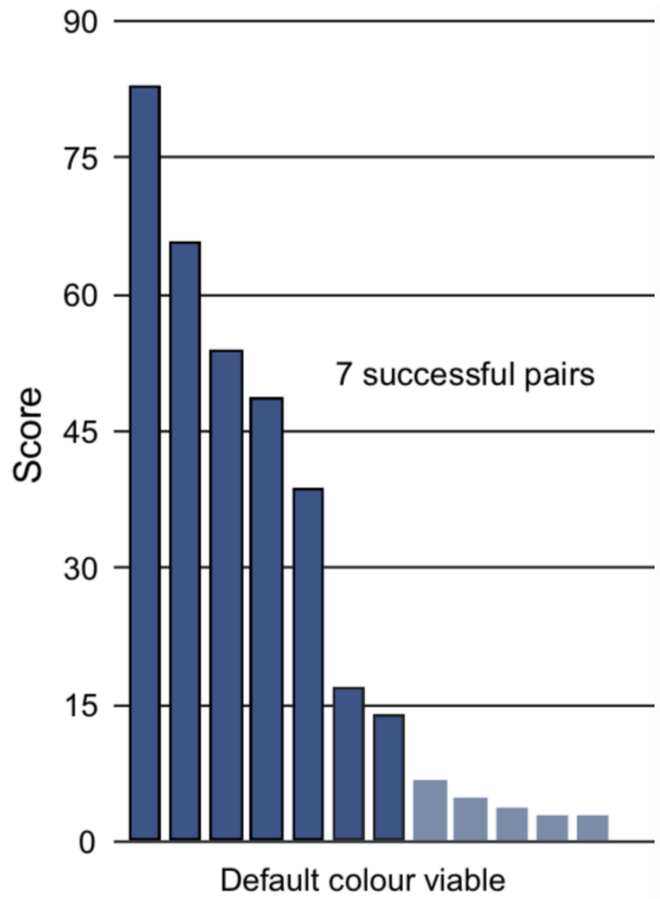


Fig. 5. Comparison of performance between original condition and condition where default colour could not achieve success. Each bar refers to one pair, with their final score on the *y*-axis. The darker-coloured bars are those pairs that reported success; the lighter-coloured ones those that reported failure. The difference between the two conditions is significant both in terms of the number of pairs that achieved success ($\chi^2_1 = 4.44$, $p = .035$) and the average score achieved in each condition ($t_{22} = 2.39$, $p = .026$).

RESULTS EXPERIMENT 1

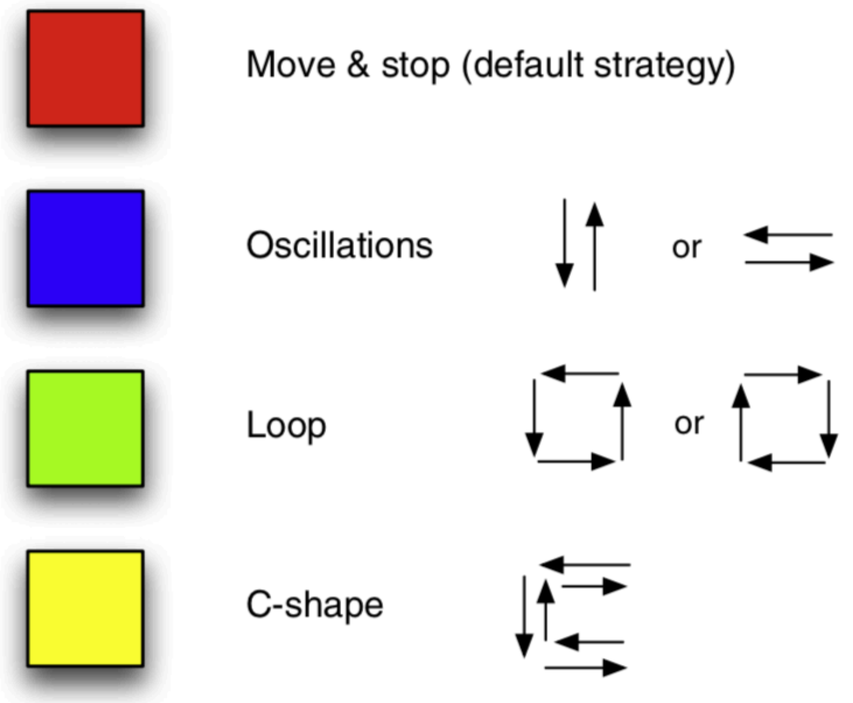


Fig. 2. A typical emergent system. In this communication system red is the default colour. If participants have a red square, they move to it and wait. If they do not have red they will signal one of the other colours by using the movements indicated. If one participant signals a colour that the other participant also has, that participant will move to the relevant square and hit space to end their turn. Otherwise, the participants will signal alternative colours until an agreement is reached. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

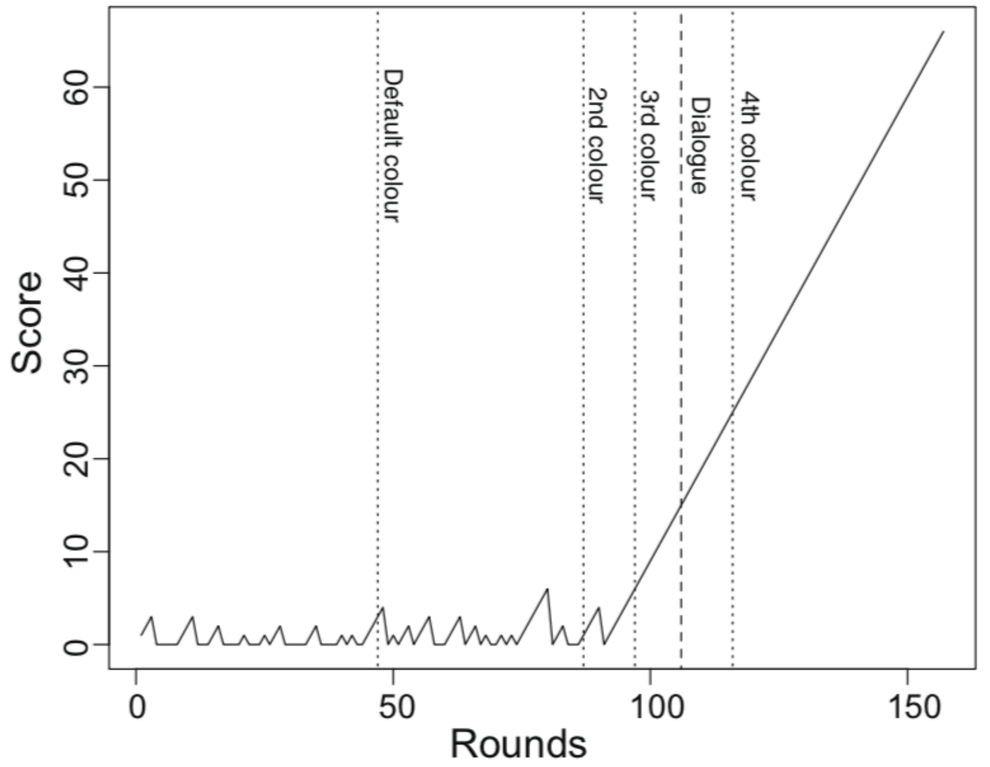


Fig. 4. An example of one pair's progress. Along the *x*-axis is the total number of rounds played and along the *y*-axis the points-in-succession score. As can be seen, initially the pair does not score significantly above chance, but as they establish behaviours for each colour they achieve better points-in-succession scores, eventually hitting upon a full-proof system that is able to score a point in every round.

RESULTS EXPERIMENT 1

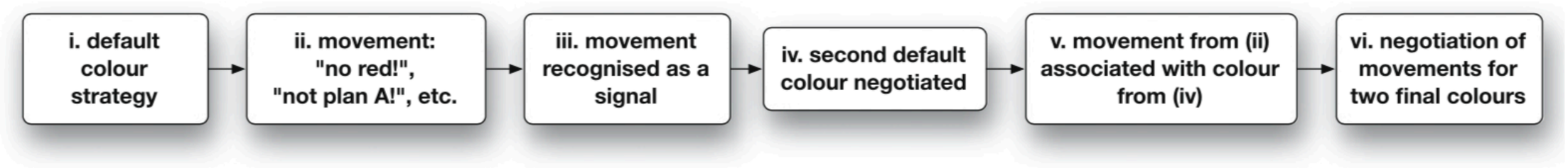
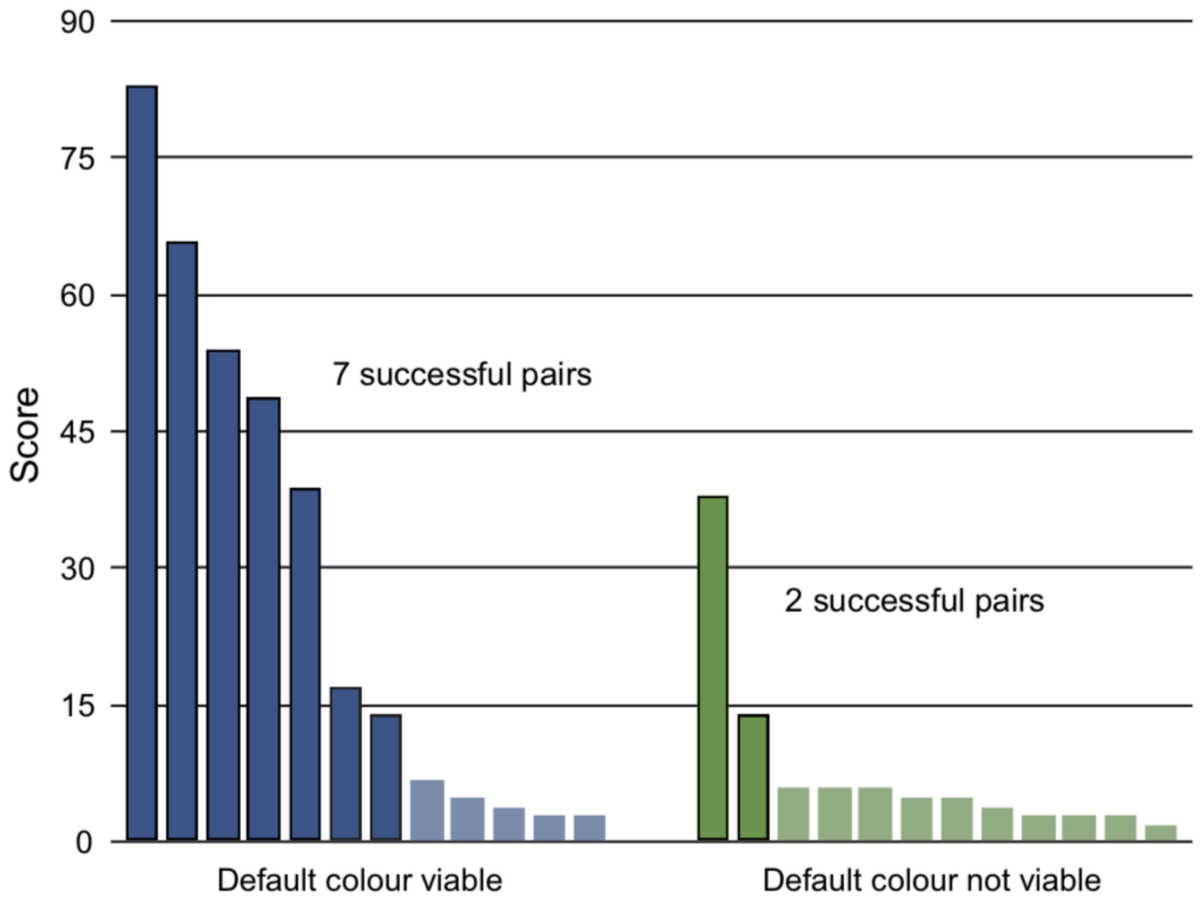


Fig. 3. Stages in the development of successful communication systems. First, in (i), the participants converge upon some shared default colour, usually (in 4 of 5 cases) red. In (ii) one participant performs some movement that would be otherwise unexpected – typically oscillations or circles around the box. This is designed to tell the other participant that this participant does not have the default colour available. This movement must then (iii) be recognised as a signal by the other player. As a result different colours to the default are chosen, and soon (iv) the two participants agree on a second-choice colour that they use when one or the other of them does not have the default colour. Then, in (v), the movement used in (ii) comes to mean, through repeated use, the colour chosen in (iv). Finally, (vi) now that such a symbol has been established the participants find it straightforward to agree on symbols for the remaining two colours. They consequently develop a system like that in Fig. 2. This enables them to score in every round and hence build a very high points-in-succession score.

SETUP EXPERIMENT 2

- participants: 12 pairs of participants
- procedure: each pairs plays for 40 minutes uninterrupted (after a 3 min training phase); each agent moves around until they decide on a quadrant;
- trials: colors assigned to quadrants where random except that players must have at least one color in common and that **the previous "winning color" was never present in the subsequent trial**
- points: longest streak of subsequent successes

RESULTS EXPERIMENT 1



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