THE CO-EVOLUTION OF COMMUNICATION AND COOPERATION: LEWIS SIGNALLING GAMES IN SOCIAL DILEMMA SCENARIOS

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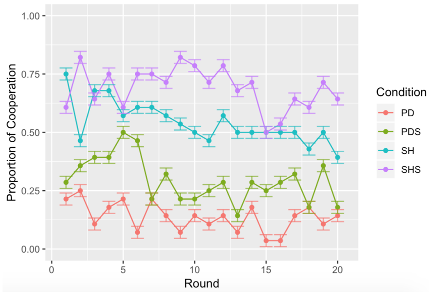
For communication to emerge and persist in a population, it should be adaptive for both senders and receivers (Skyrms, 2010). However, many social interactions involve conflicts of interest, mis-matches between personal and collective goals, or the temptation to minimize individual risk or free-ride (Sterelny, 2012). Humans are particularly successful at resolving these issues — but as this skill is often attributed to our use of language (Smith, 2010), it appears that language and sociality are evolutionary pre-requisites for each other. This lends weight to theories such as the Interdependence Hypothesis (Tomasello et al., 2012), which argue for the co-evolution of cooperation and communication. However, relatively few accounts of signalling consider more complex social scenarios; modelling work (Santos et al., 2011) has shown that signalling leads to improved group and individual outcomes in repeated *social dilemma* games, where signals serve as 'secret handshakes', i.e. social identifiers, rather than honest signals of intended strategies. Our experimental study investigates which strategies are used by interacting groups of human participants: honest signals, social identifiers, or otherwise.

Methods

112 participants were recruited to play repeated social dilemma games in groups of four, using the online platform oTree (Chen et al., 2016). The two games were i) the *stag hunt*, where individual and common interest coincide, but risk-avoidance strategies are available, and ii) the *prisoner's dilemma*, where defection is individually preferable in any single game, but cooperative strategies are mutually beneficial in the long-term. Groups were allocated to one of four conditions: two conditions without signalling (SH & PD), and two with bidirectional pre-play signalling (SHS & PDS), with 6 graphical signals with no pre-established meaning made available. The four participants within each group were anonymously paired at random for each of 20 rounds of play. Individual and group behaviour was measured as the proportion of cooperative decisions made across rounds; for signals S, decisions D, and identities I, conditional entropy was used to measure the



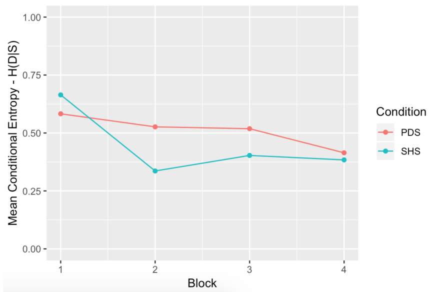


Figure 1. On the left, the mean proportion of cooperation across rounds for the different conditions. On the right, the conditional entropy of decisions given signals $H(D|S)$ across blocked rounds in the SHS (stag hunt with signals) and PDS (prisoner's dilemma with signals) conditions.

informativity over time of $H(S|D)$, $H(D|S)$, $H(S|I)$, and $H(I|S)$.

Results and discussion

1) *Cooperation*: in a linear mixed effects logistic regression with participant nested within group as a random effect, more cooperation was found in stag hunt conditions SH & SHS than in prisoner's dilemma conditions PD & PDS ($\beta = 2.64,\ S.E. = 0.36,\ z = 7.26, p \ll 0.001$; see Fig.1, left). While there was no significant difference between SH and SHS, participants in PDS cooperated more than in PD ($\beta = 0.99,\ S.E. = 0.16,\ z = 6.35, p \ll 0.001$). Finally, cooperation decreased across rounds overall across conditions ($\beta = -0.023,\ S.E. = 0.01,\ z = -2.37, p < 0.05$).

2) *Signal information*: in a linear mixed effects regression including group as a random effect, $H(D|S)$ decreased across blocks ($\chi^2(1) = 4.26, p < 0.05$) by 0.06 ± 0.03 bits per block (see Fig.1, right). The conditional entropy $H(S|D)$ was lower in PDS than SHS ($\chi^2(1) = 14.64, p < 0.001$) by 0.49 ± 0.13 bits. $H(S|I)$ was lower in condition SHS ($\chi^2(1) = 15.92, p < 0.001$ by 0.46 ± 0.11 bits.

The higher levels of cooperation in the signalling conditions supports the general hypothesis that communication promotes cooperation. The slight decrease in cooperation over time across conditions, on the other hand, may be due to the destabilising influence of non-cooperative strategies, to which both scenarios are vulnerable, and potentially even retributive strategies such as punishment and/or spite. However, participants in the signalling conditions did not resort to indiscriminate defection, suggesting the use of more complex coordination strategies. The decrease in $H(D|S)$ combined with the higher levels of cooperation in the signalling conditions implies that, over time, signals served to reduce uncertainty about opponents' strategies. This suggests that, rather than the emergence of social identifiers as predicted by Santos et al (2011), honest signalling plays a role in the development and maintenance of cooperation.

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