Supplementary Material

The Evolution of Individual Variation in Communication Strategies

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Contents: (1) Alternative signaling strategies in the absence of errors in self-perception; (2) Analytical model of the coexistence of personality types; (3) Individual-based simulation model of dynamic signals; and (4) five additional figures.

(1) Alternative signaling strategies in the absence of errors in self-perception

In this simplified version of our individual-based simulation model, we varied the rules that determine the outcome of fights. If both opponents choose to attack, the stronger individual always wins. If the opponents are equally matched, the winner is determined by coin toss. Quality is constant throughout lifetime and errors in self-perception are applied at both badge production and the interaction phase. All other details of the model remain unchanged. Under these conditions, two distinct communication strategies are observed at $\sigma_E = 0$ and additional strategies are observed when the potential for error in self-perception is increased (Fig. SM1). This model formulation is somewhat unrealistic because of the disproportionate effects that extremely small quality differences can have over the probability of winning. However, it allows us to show that under certain conditions polymorphisms in communication strategies might also be observed in the absence of self-perception errors. Note that the polymorphism observed when $\sigma_E = 0$ is a product of individual differences in sender but not receiver codes (Fig. SM1 A), suggesting alternative ways in which senders exploit the average population behavior. As expected, this polymorphism is highly unstable: in all replicate simulation runs with $\sigma_E = 0$ (n=100), the population cycled multiple times between monomorphic and polymorphic states. Introducing errors in self-perception to this model led to more stable polymorphisms in which alternative strategies differed in both sender and receiver behavior as in the model presented in the main text (Figs. SM1 B-D).

(2) Analytical model of the coexistence of personality types

In this simplified model individuals can be strong (s) or weak (w) and they can produce a badge or not. The cost (C) of signal production is dependent on individual quality such that $C_s < C_w$. Individual strategies are vectors with the following values: Probability of producing a badge when strong, Probability of producing a badge when weak, Probability of attack when strong and rival has a badge, Probability of attack when strong and rival does not have a badge, Probability of attack when weak and rival has a badge, and Probability of attack when weak and rival does not have a badge. Thus, a simple approximation of the strategies that emerge in our individual-based simulation model at $\sigma_E = 0.15$ can be represented as:

Aggressive = [1, 1, 1, 1, 0, 1]
Moderate = [1, 0.5, 1, 1, 0, 0.5]
Conservative = [1, 0, 0, 1, 0, 0]

This strategy set leads to the following payoff matrix A (payoffs are given for the row player):

	Conservative	**Moderate**	**Aggressive**
Conservative	$0.25V - 0.5C_s$	$0.125V - 0.5C_s$	$-0.5C_s$
Moderate	$0.625V - 0.5C_s - 0.25C_w$	$0.430V - 0.133L$ $-0.5C_s - 0.25C_w$	$0.375V - 0.125L$ $-0.5C_s - 0.25C_w$
Aggressive	$0.75V - 0.5C_s - 0.5C_w$	$0.5V - 0.125L$ $-0.5C_s - 0.5C_w$	$0.375V - 0.125L$ $-0.5C_s - 0.5C_w$

To determine how the frequency of these strategies varies over time, we used the discrete form of the replicator dynamics (Hofbauer and Sigmund 1988),

$$x_i' = x_i \frac{f_i}{\bar{f}}$$

in which x_i is the proportion of type i, $f_i = \sum_j x_j A_{ij}$ is the fitness of type i, and $\bar{f} = \sum_j x_j f_j$ is the weighted average of the fitness of the three types. It can be shown that under realistic assumptions (i.e., $C_w << V < L$), the system will always exhibit the dynamics shown in Figure 6 of the main text (Fig. 6 was plotted based on the following parameters: $V = 1$, $L = 3$, $C_s = 0.015$, and $C_w = 0.15$).

(3) A model of dynamic signals

Our model of badges of status assumes that signals are constant throughout lifetime, that there is a time-lag between signal production and signal use, and that signal costs are expressed only in terms of survival. To explore the generality of our findings we modified the basic individual-based simulation model so that new signals were produced each time they were used (such as in the crest-erection threat displays of in jays and other birds (Hardy 1974)). Signal costs in this version of the model were modelled as a reduction in payoff such that

$$\text{Signal cost} = k_0/(1+\exp\left[k_1 + k_2(Q-C)\right]),$$

where Q is the individual's own quality, C is the intensity of crest erection, and k_0, k_1,and k_2 are scaling constants.

The results of this model are qualitatively identical to those of the model with badges of status (Fig. SM5). When $k_0 = 5$, $k_1 = 3$, and $k_2 = 6$, populations converge into a single communication strategy at $\sigma_E = 0$ (n=100, mean ± SE = 1.00 ± 0.0 clusters), two stable communication strategies at $\sigma_E = 0.1$ (n=100, mean ± SE = 2.35 ± 0.05 clusters), and three distinct communication strategies at $\sigma_E = 0.2$ (n=100, mean ± SE = 3.17 ± 0.06 clusters).

Literature cited

Hardy, J. W. 1974. Behavior and its evolution in Neotropical jays (Cissilopha). Bird-Banding 45:253-268.

Hofbauer, J., and K. Sigmund. 1988. The Theory of Evolution and Dynamical Systems Cambridge University Press, Cambridge, UK.

Figure SM1. Mean sender and receiver codes predicted by our alternative formulation of the model of badges of status with different amounts of error in the sender's estimation of own quality. Errors in self-perception are drawn from N(μ = 0.5, σ = σ_E). (A) σ_E = 0.0, (B) σ_E = 0.05, (C) σ_E = 0.1, and (D) σ_E = 0.2.

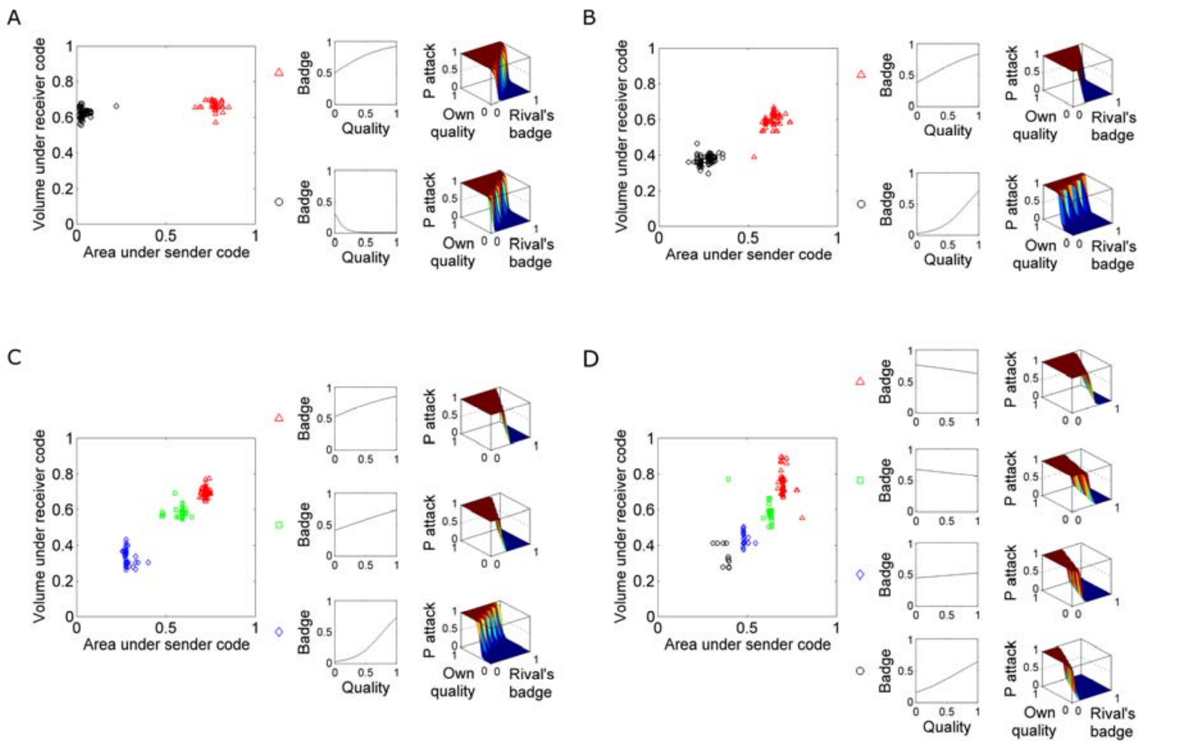

Figure SM2. Individual variation in communication strategies in a representative replicate simulation run with quadratic logistic communication codes and σ_E = 0.1.

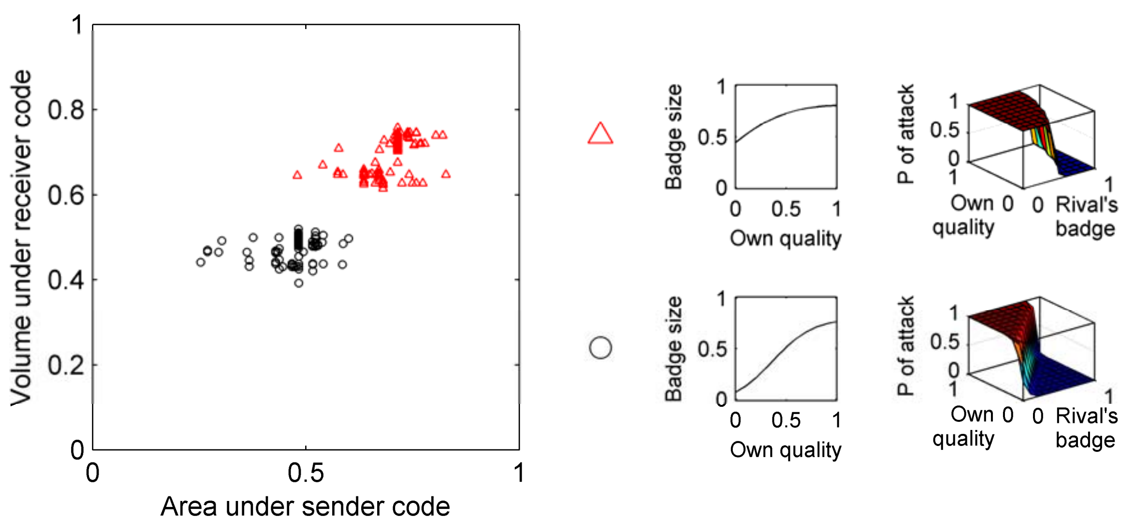

Figure SM3. Individual variation in communication strategies in a representative replicate simulation run with sexual reproduction, recombination rate of 0.5, and σ_E = 0.15. This version of the model includes a sixth locus that simultaneously modifies the value of the points of inflection. Thus, $a_s = a_s' + m$ and $a_r = a_r' + 1.5m$, where *m*, a_s' and a_r' are alleles inherited from the parents.

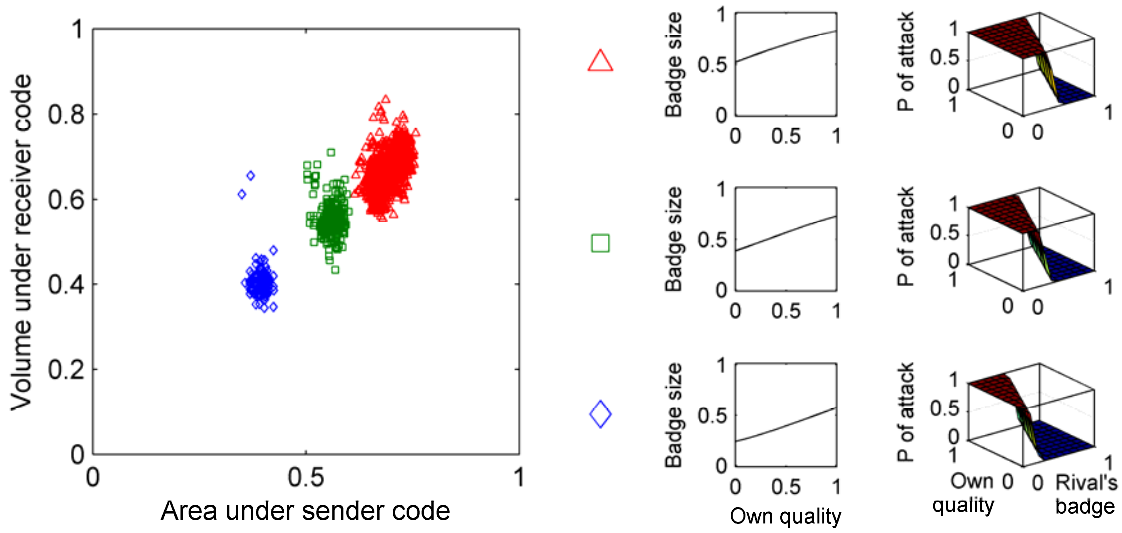

Figure SM4. Histogram of trait values for the *m* locus in the replicate simulation run of the sexual recombination model depicted in Fig. SM3. The distribution of *m* is clearly trimodal and each peak corresponds to one of the main strategies observed in Fig SM3 (see color-coding).

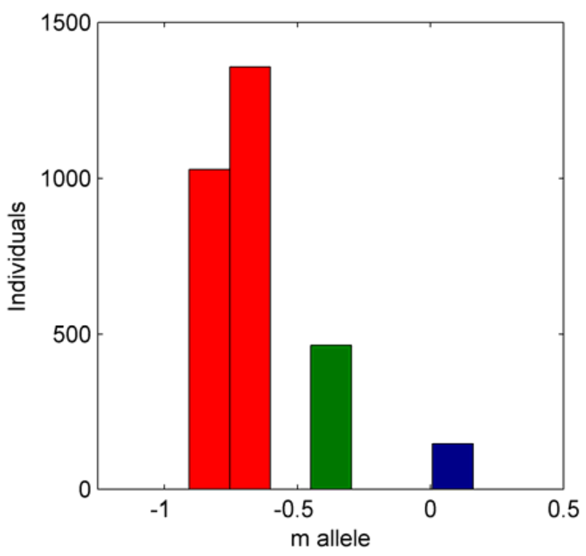

Figure SM5. Mean sender and receiver codes predicted by our model of dynamic signals (e.g. crest erection in birds) with different amounts of error in the sender's estimation of own quality. Errors in self-perception are drawn from N(μ = 0.5, σ = σ_E). (A) σ_E = 0.0, (B) σ_E = 0.1, (C) σ_E = 0.15, and (D) σ_E = 0.2.