Citation for published version:
Darden, S, James, R, Cave, J, Bohr Brask, J & Croft, D 2020, 'Trinidadian guppies use a social heuristic that can support cooperation among non-kin', *Proceedings of the Royal Society B*, vol. 287, no. 1934, 0487. https://doi.org/10.1098/rspb.2020.0487

DOI:
10.1098/rspb.2020.0487

Publication date:
2020

Document Version
Peer reviewed version

Supplementary material for:

Trinidadian guppies use a social heuristic that can support cooperation among non-kin

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Section 1: Evidencing that a 'Walk Away' social heuristic can lead to assortment of cooperative agents in a population with fission-fusion group dynamics

Social structures based around dynamic group membership are ubiquitous within the animal kingdom [1, 2]. Since previous models investigating the extent to which a 'Walk Away' rule can drive positive assortment by propensity to cooperate have not captured these social dynamics [3-5, but see 6 where individuals can leave a group prior to any interaction], it is unclear if a 'Walk Away' rule can generate such assortment in systems where groups stochastically split and merge (i.e. the dynamic fission and fusion of groups typifying many social species). We therefore use a simulation model to explore the proposition that a 'Walk Away' heuristic can generate positive assortment of social interactions by individual cooperative phenotypes in the highly dynamic social environments that typify many social vertebrates.

We implemented an agent-based, steady-state stochastic simulation model of fission and fusion in the spirit of existing merge and split models [7, 8] to generate conditions representing a highly dynamic fission-fusion system (see detailed methods below). Our key addition was that the phenotypes of the group members (45 obligate co-operators and 45 obligate defectors, each with a given tolerance for defection, E_i) played a part in determining the membership of daughter groups after fission. Briefly, in our model, we associated each fission event of a parent group with a public-goods game, yielding a return R for each group member. An individual's satisfaction at the outcome of the game was $S_i=R-E_{ii}$, where E_i is the individual's 'tolerance' for defection (see detailed methods below). Satisfied agents ($S_i \geq 0$) joined either of two daughter groups with equal probability. Dissatisfied agents ($S_i < 0$) could 'Walk Away', either by forming a new group of their own, or by joining any one of the other groups in the population, including the two daughter groups (Fig. S1A,B). From the simulation we collected 2500 independent censuses (every 10,000 timesteps) of group membership to form a weighted network of associations (see detailed methods below). As a control, we ran a neutral model where we randomised the membership of the groups recorded in each census in the 'Walk Away' model.

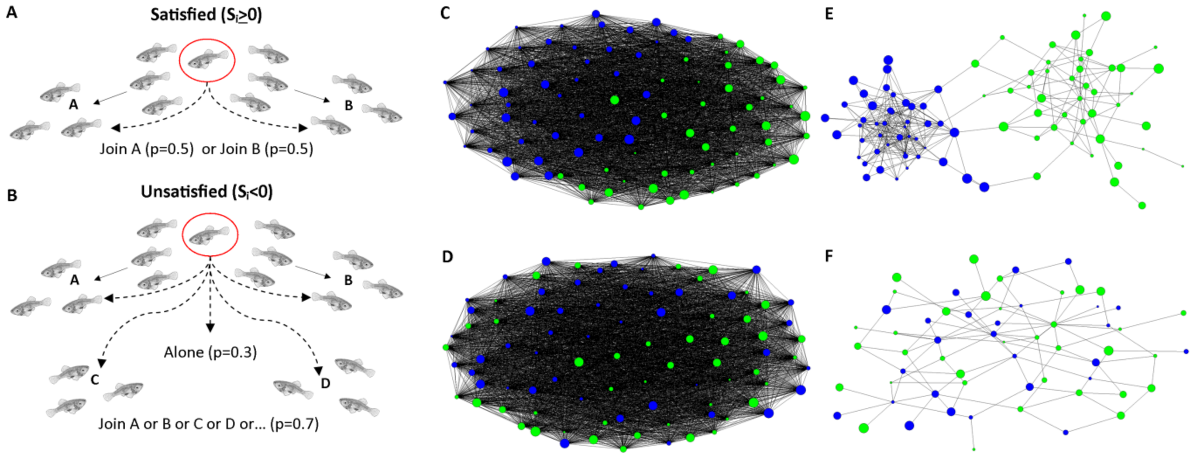

Fig S1. Simulation model 'Walk Away' rule implementation with illustrative graphical output. (A-B) Individual conditional movement decisions made at group fission when a 'Walk Away' rule is imposed on an agent-based, steady-state simulation model with fission–fusion dynamics. (A) 'Satisfied' individuals are those whose minimum return from being in the group is met ($R-E_i>0$, see text), while (B) 'unsatisfied' individuals are those whose minimum have not been met ($R-E_i<0$). (C-F) Graphs of interactions between agents in the model whose association indices are greater than (C-D) 0.042 and (E-F) 0.06 with (C,E) a 'Walk Away' rule imposed and (D,F) a neutral model. Node colour indicates phenotype (green=co-operator, blue=defector), node size indicates, E, as higher (smaller nodes due to lower E) and lower (larger nodes due to higher E) tolerance for defection (range 0.2-0.8), lines indicate dyadic connections greater than the respective filtering thresholds.

The results of the model demonstrate that even against a dynamic background of fission and fusion, a simple 'Walk Away' rule can drive social assortment by cooperative phenotype (Fig. S1C,E and Fig. S2); when agents use a walk away strategy, the assortment of social ties by cooperative phenotype within the population become significantly greater than zero with increasing tie strength, which is not the case in a neutral model (Figs. S1D,F, S2A and S3)**.**

Detailed methods

Agent-based simulation model

The model population consisted of 90 agents, 45 obligate co-operators and 45 obligate defectors. Agents were in groups, whose size and composition were subject to fission-fusion dynamics implemented through probabilistic rules. At each timestep there was a small probability ($3.5 \times 10^{-5}\sqrt{(s_1 s_2)}$) that two groups of size s_1 and s_2 would fuse to form a group of size s_1+s_2; thus large groups were more likely to fuse than were small groups. There was also a small constant probability (0.004, irrespective of size) that a given group would split and decision rules were implemented at these fission events. Our split and merge rules allowed us to mimic a biologically realistic monotonically decreasing group size as typically observed in fission fusion social systems [9].

Each agent was assigned a phenotype along a gradient of values, spread evenly in the range 0.2 to 0.8, that determined its "expectation", E_i, of the cooperative behaviour of others in the group. For example, the lowest E-values (0.2 to 0.4) had lower expectations and therefore can be considered more ‘tolerant’ of defection. At the moment of fission we assumed that the focal group had just undergone a cooperative game. Each co-operator in the group contributed 1 point to a shared “pool”, defectors contributed 0. The value of the pool was multiplied by 1.9 [as in 3, 4], then shared equally among all group members. This “return” from the game, R, minus an agent’s expectation E_i, determined its ‘satisfaction’ with being in the group at the time of the fission event: $S_i=R-E_i$. The satisfied agents (those with $S_i \geq 0$) split into two daughter groups (Fig. S1). Each satisfied agent had a 50% chance of being placed in each of the two groups. Agents that were not satisfied ($S_i<0$) had a tendency to ‘walk away’; they either formed a group of N=1 or joined an existing group with equal likelihood of joining any particular group, including each of the daughter groups formed by the fission of satisfied agents (Fig. S1). After 50,000 timesteps at which point the model had reached steady-state (dynamic equilibrium), we monitored group membership every 10,000 timesteps, in a series of 2,500 censuses of the population. The 10,000 timestep interval was derived from our expectation in the neutral model that every agent had had the opportunity to be in a group with every other agent over that period, which allowed us to produce censuses free of sequential correlation. For these associations we constructed a weighted 90x90 association

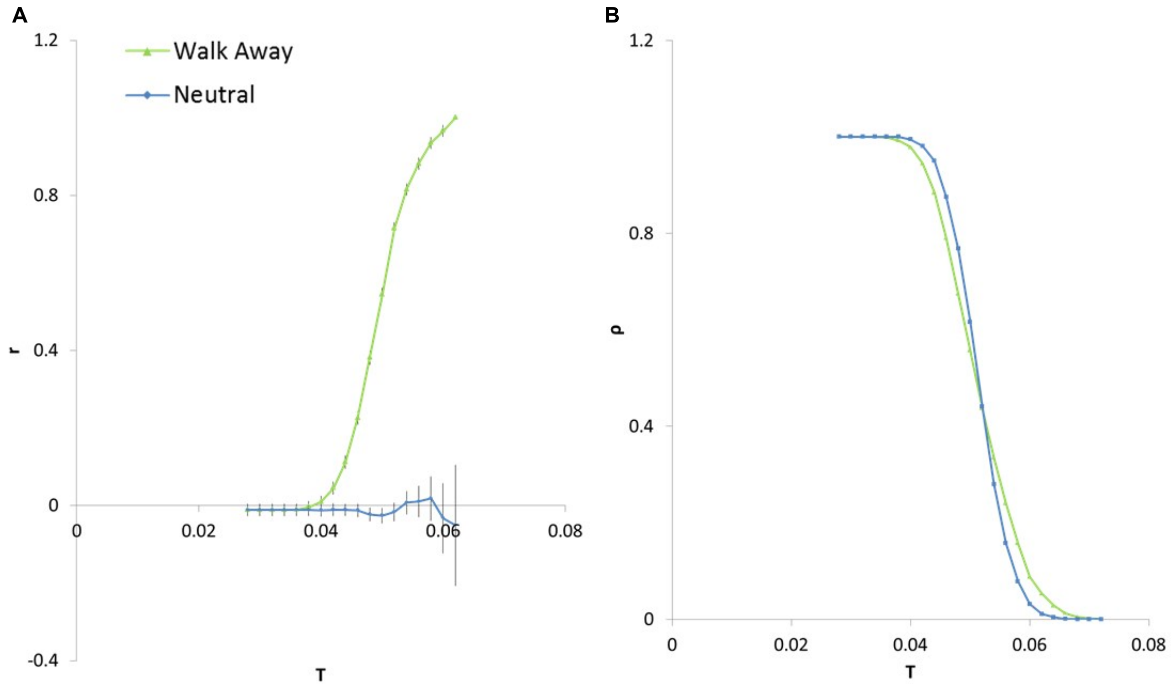

Fig S2. Assortment by cooperativeness in the social networks sampled from an agent-based, steady-state simulation model with fission–fusion dynamics. (A) The assortivity coefficient, r, is an indicator of the overall assortivity of associations in the population by cooperative phenotype (see Methods) with a ‘Walk Away’ rule imposed (green) and without such a rule (blue). T is the threshold over which agents must associate to be assigned a tie strength of one in a binary association matrix. Error bars = +/- 1σ and indicate whether the value of r differs from zero at a given T (see Methods). (B) The fraction of ties, ρ, that have an association index greater than our filtering threshold, T, in our ‘Walk Away’ and neutral models. The decrease reflects the fact that a smaller fraction of the population had stronger ties.

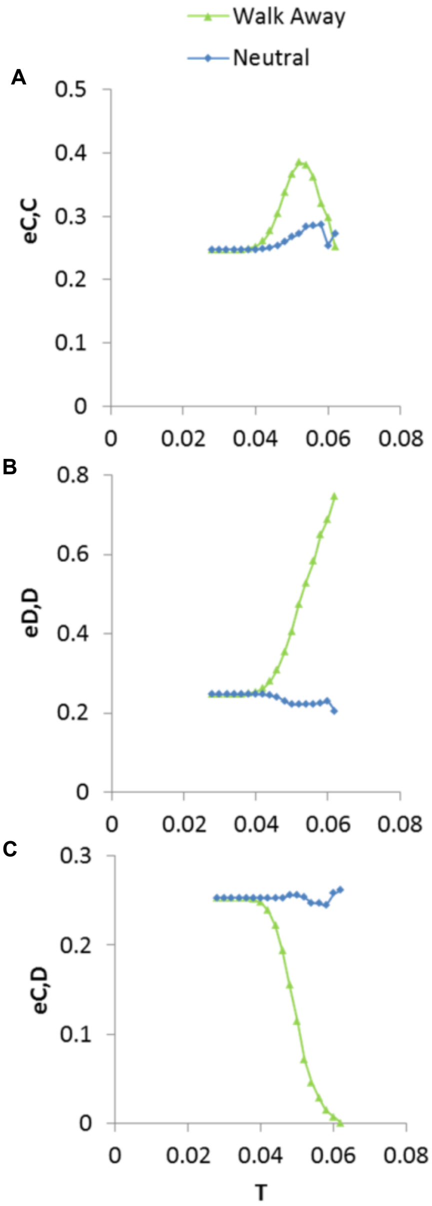

Fig. S3. Frequency of tie 'types' in the sampled networks. (A-C) The proportion of edges in the network, e, that are represented by the three phenotypic dyad types (C,C = co-operator-co-operator, C,D = co-operator-defector, D,D = defector-defector) with the 'Walk Away' rule implemented (green) and in the null model (blue).

matrix W, whose entry W_{ij} was the fraction of censuses in which agents i and j were in the same group. All agents occurred at least once with all others, so all $W_{ij}>0$. Our neutral model used the same group sizes as the original model at every census, but the groups were populated randomly with respect to S.

Analysis of simulation data

To analyse whether the implementation of a 'Walk Away' rule was sufficient to maintain long-term assortment in our population, despite rapid fission-fusion dynamics, we constructed a series of binary matrices A(T) whose entry $A_{ij}(T)$ was 1 if $W_{ij} \geq T$, and 0 otherwise. T is a threshold fraction of times agents were found in the same group in our 2,500 censuses. As T increased, the density of A (ρ , the fraction of elements that are 1) decreased reflecting the fact strong associations were found between a smaller fraction of agents (Fig. S1). For each A(T), we computed Newman's assortativity coefficient r [10] which measures whether there are more CC and/or DD pairs in our groups than if edges were wired at random (Fig. S2). This is our measure of assortment in the population. A jack-knife procedure was used to test whether the computed values of r were significantly greater than zero in each of our models [10].

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Section 2: Supplementary detail on methods and results of the main experiment.

Table S1. Number of focal individuals tested at each level in the study's main experiment. N denotes the number of biological replicates (focal individuals).

Inspection condition	**Social experience**	**Diet type (inspection phase)**	**N**
No predator present	Cooperation	Bloodworm	14
		Daphnia sp.	16
		Total	**30**
	Defection	Bloodworm	16
		Daphnia sp.	17
		Total	**33**
	Total	Bloodworm	30
		Daphnia sp.	33
		Total	**63**
Predator present	Cooperation	Bloodworm	16
		Daphnia sp.	17
		Total	**33**
	Defection	Bloodworm	16
		Daphnia sp.	17
		Total	**33**
	Total	Bloodworm	32
		Daphnia sp.	34
		Total	**66**
Total	Cooperation	Bloodworm	30
		Daphnia sp.	33
		Total	**63**
	Defection	Bloodworm	32
		Daphnia sp.	34
		Total	**66**
	Total	Bloodworm	62
		Daphnia sp.	67
		Total	**129**

Table S2. Results of the analysis of the main experiment testing for an effect of the inspection condition that fish were in (no predator present, i.e. control, versus predator present, i.e. experimental), the social environment that fish experienced during the inspection portion of a trial (cooperative vs. non-cooperative), the type of diet (daphnia or bloodworm) that novel shoaling partners had been fed on and their interactions including the inspection behaviour of focal individuals in the model (removed in final model). *Note:* we did not have inspection data for 4 focal individuals in the control inspection condition (no predator present) due to video failures.

Source	*F(1,116)*	*p*
Inspection behaviour	0.393	0.532
Inspection condition	0.749	0.388
Social experience	5.915	**0.017**
Diet type	5.171	**0.025**
Inspection condition * Social experience	5.714	**0.018**
Inspection condition * Diet type	0.015	0.903
Social experience * Diet type	2.517	0.115
Inspection condition * Social experience * Diet type	0.116	0.734