Supplementary Material

SI Text: finding the optimal distance in attention-space, Z*

In order to quantify how much competition reduction foragers gain from attentional character displacement, we created a measure, Z, that captures the distance in attention space between a forager and all other members of the group (see main text for details). Z expresses the Euclidean distance in *M*-dimensional space between group members. Here, we derive the maximal possible value of Z, which we denote Z*. This value can be used to determine how effective groups are at taking advantage of the benefits of attention modulation. Z* depends on the group size, N, the number of prey types, *M*, and on the proportion of the group that can modulate their attention, *PopQ*.

We begin with the simpler case, where *PopQ* = 1 and all foragers can move in attention space. We note one additional key restriction: in our model, each forager's attention is fully engaged at all times, so that the sum of its attention to all prey types must equal 1. Under these constraints, the ideal position for any forager is at one edge of attention space, where its attention is fully engaged in one prey type. There are *M* such edges in the space.

In cases where $M \geq N$, each forager can focus on a different prey type and the distance between all pairs of foragers, as well as the mean distance, will be

$$Z^* = \sqrt{2} \qquad \text{(Equation S1)}$$

If $M < N$, some agents will co-occupy the same edges of attention-space (i.e., be focused on the same prey type). Of the *M* possible edges, N *mod M* edges will house $\lceil N/M \rceil$ (the ceiling of N/*M*, the closest integer rounding the fraction up). The remaining *M* - (N *mod M*) edges will house $\lfloor N/M \rfloor$ (the floor of N/*M*, rounding the fraction down). In each case, foragers have a distance of $\sqrt{2}$ from those occupying other edges and a distance of 0 from those occupying the same edge as themselves. As a result, foragers in the more densely occupied edges will experience a mean distance from all others of $((N - \lceil N/M \rceil)\sqrt{2})/(N-1)$ and foragers at the other edges will experience a mean distance of $((N - \lfloor N/M \rfloor)\sqrt{2})/(N-1)$. In sum, then, the mean maximal distance attainable by the agents is:

$$Z^* = (((N \mathit{ mod } M)\lceil N/M \rceil(N - \lceil N/M \rceil)\sqrt{2}) / (N - 1) +$$
$$(M - (N \mathit{ mod } M))\lfloor N/M \rfloor(N - \lfloor N/M \rfloor)\sqrt{2}) / (N - 1)) / N \qquad \text{(Equation S2)}$$

Equation S2 will simplify to Equation S1 in cases where $M \geq N$.

The more difficult case is when *PopQ* < 1 and only some of the foragers can move in attention space. For legibility, we here denote *PopQ* as simply q. In this case, only qN foragers are free to move in attention space. Their optimal positioning is still at the edges of the space. The distances between them will be as above. In addition, however, they will each have a smaller distance from those foragers that cannot move, whose attention remains at $1/M$ on each dimension of attention space. Distances between members of the two phenotypes will be $\sqrt{(M-1)/M}$, and there will be $(1 - q)N$ of these. There will therefore be three possible distances:

$$A = ((qN - \lceil qN/M \rceil)\sqrt{2} + (1 - q)N\sqrt{(M-1)/M}) / (N-1) \qquad \text{(at a more populated edge)}$$

$$B = ((qN - \lfloor qN/M \rfloor)\sqrt{2} + (1 - q)N\sqrt{(M-1)/M}) / (N-1) \qquad \text{(at a less populated edge)}$$

$$C = qN\sqrt{(M-1)/M} \qquad \text{(in the center)}$$

Combining these with the numbers in each condition gives:

$$Z^* = ((qN \mathit{ mod } M)\lceil qN/M \rceil A +$$
$$(M - (qN \mathit{ mod } M))\lfloor qN/M \rfloor B + (1 - q)C) / N \qquad \text{(Equation S3)}$$

Figure S6 shows the values of Z* for a range of values of N, *M*, and *PopQ*.

Table S1. Results of linear regressions on the data in Figure 2B and 2C, for success rate. A separate regression was run on the data for each group size (N) and each phenotype (Q0 or Q1) across all values of *PopQ*. The table gives the F-ratio (with degrees of freedom), P-value, and regression coefficient (*b*) for each line.

N	Q0 foragers			Q1 foragers		
	F	P	*b*	F	P	*b*
2	F(1,98) = 0.99	0.32	-0.001	F(1,98) = 2.75	0.10	-0.003
5	F(1,248) = 38.5	< 0.00001	-0.003	F(1,248) = 92.3	< 0.00001	-0.005
10	F(1,498) = 151	< 0.00001	-0.003	F(1,498) = 389	< 0.00001	-0.008

Table S2. Proportion of prey taken that are of type 2 as a function of *PopQ* and K_2. A separate 2-way ANOVA was run for each group size (N). Each column shows one effect (K_2, *PopQ*, and their interaction) and each cell gives the F-ratio, P-value, and effect size (η^2) for that effect. Significant post-hoc (PH) comparisons (for which $p < 0.01$) are noted below each cell. The top table gives results for Q1 foragers, and the bottom table for Q0 foragers.

Q1 foragers:

N	K_2	*PopQ*	K_2 * *PopQ*
2	$F(5,887) = 233$, $P < 0.001$, $\eta^2 = 0.52$	$F(1,887) = 0.09$, $P = 0.76$, $\eta^2 = 0.00004$	$F(5,887) = 2.67$, $P = 0.02$, $\eta^2 = 0.006$
	PH: all different except 1 vs. 0.8 and 0.9	PH: no difference	
5	$F(5,4469) = 19.79$, $P < 0.001$, $\eta^2 = 0.43$	$F(4,4469) = 0.30$, $P = 0.88$, $\eta^2 = 0.0001$	$F(20,4469) = 0.37$, $P = 1.00$, $\eta^2 = 0.0007$
	PH: all different except 0.9 vs. 0.8 and 1	PH: no differences	
10	$F(5,16435) = 2393$, $P < 0.001$, $\eta^2 = 0.335$	$F(9,16435) = 5.01$, $P < 0.001$, $\eta^2 = 0.001$	$F(45,16435) = 0.78$, $P = 0.86$, $\eta^2 = 0.001$
	PH: all different except 0.9 vs. 1	PH: 0.9 and 1 different from 0.3 and 0.4	

Q0 foragers:

N	K_2	*PopQ*	K_2 * *PopQ*
2	$F(5,888) = 184.3$, $P < 0.001$, $\eta^2 = 0.48$	$F(1,888) = 0.007$, $P = 0.93$, $\eta^2 = 0.000004$	$F(5,888) = 0.60$, $P = 0.70$, $\eta^2 = 0.002$
	PH: all different except 0.9 vs. 0.8 and 1	PH: no difference	
5	$F(5,4468) = 612$, $P < 0.001$, $\eta^2 = 0.35$	$F(4,4468) = 1.06$, $P = 0.38$, $\eta^2 = 0.0005$	$F(20,4468) = 0.58$, $P = 0.93$, $\eta^2 = 0.001$
	PH: all different except 0.9 vs. 0.8 and 1	PH: no differences	
10	$F(5,16427) = 1406$, $P < 0.001$, $\eta^2 = 0.25$	$F(9,16427) = 5.77$, $P < 0.001$, $\eta^2 = 0.002$	$F(45,16427) = 1.29$, $P = 0.09$, $\eta^2 = 0.002$
	PH: all different except 0.9 vs. 1	PH: 0 different from 0.4, 0.6 and 0.9	

Table S3. Results of linear regressions on the data in Figure 3, for distance in attention-space (Z). A separate regression was run on the data for each group size (N) and each phenotype (Q0 or Q1) across all values of *PopQ*. The table gives the F-ratio (with degrees of freedom), P-value, and regression coefficient (*b*) for each line.

N	Q0 foragers			Q1 foragers		
	F	P	*b*	F	P	*b*
2	$F(1,98) = 4749$	< 0.00001	0.72	$F(1,98) = 621$	< 0.00001	-0.39
5	$F(1,248) = 15521$	< 0.00001	0.42	$F(1,248) = 1035$	< 0.00001	-0.20
10	$F(1,498) = 31553$	< 0.00001	0.33	$F(1,498) = 1132$	< 0.00001	-0.12

Table S4. Results of Paired-sample T-tests comparing the distance in attention-space (Z) achieved by Q0 foragers and Q1 foragers, at each level of *PopQ* (excluding 0 and 1). The table gives the t-test statistic (all *df* were 299) and P-value for each test. Separate tables are given for N = 5 and N = 10 (this analysis was not run on N = 2 as there can be no difference in Z when there is only one forager of each phenotype).

N = 5

PopQ	Q1 mean Z	Q0 mean Z	t(299)	P
0.2	0.34 ± 0.25	0.08 ± 0.06	23.15	< 0.001
0.4	0.30 ± 0.18	0.17 ± 0.12	34.17	< 0.001
0.6	0.25 ± 0.12	0.26 ± 0.18	-0.43	0.67
0.8	0.22 ± 0.10	0.33 ± 0.23	-10.63	< 0.001

N = 10

PopQ	Q1 mean Z	Q0 mean Z	t(299)	P
0.1	0.33 ± 0.25	0.04 ± 0.03	22.77	< 0.001
0.2	0.30 ± 0.20	0.07 ± 0.05	26.33	< 0.001
0.3	0.30 ± 0.17	0.11 ± 0.07	31.62	< 0.001
0.4	0.28 ± 0.15	0.14 ± 0.09	38.40	< 0.001
0.5	0.26 ± 0.13	0.18 ± 0.12	33.34	< 0.001
0.6	0.25 ± 0.12	0.21 ± 0.14	12.50	< 0.001
0.7	0.24 ± 0.11	0.24 ± 0.16	0.78	0.63
0.8	0.23 ± 0.09	0.27 ± 0.19	-5.90	< 0.001
0.9	0.22 ± 0.09	0.30 ± 0.20	-7.92	< 0.001

Table S5. Results of one-sample T-tests comparing the distance in attention-space (Z) achieved by our simulated groups to the maximal possible. Each *PopQ* level was compared to its own maximum (excluding 0; second column of the table). The table gives the T-test statistic (all *df* were 299) and p-value for each test. Separate tables are given for N = 5 and N = 10 (this analysis was not run on N = 2).

N = 5

PopQ	Max Z	All Mean Z	t(299)	P
0.2	0.283	0.13 ± 0.10	-25.76	< 0.001
0.4	0.566	0.22 ± 0.14	-42.27	< 0.001
0.6	0.707	0.26 ± 0.14	-56.10	< 0.001
0.8	0.849	0.24 ± 0.11	-96.31	< 0.001
1	0.849	0.18 ± 0.10	-118.83	< 0.001

N=10

PopQ	Max Z	All Mean Z	t(299)	P
0.1	0.141	0.07 ± 0.05	-26.27	< 0.001
0.2	0.283	0.12 ± 0.08	-35.64	< 0.001
0.3	0.393	0.16 ± 0.10	-38.44	< 0.001
0.4	0.503	0.20 ± 0.12	-45.77	< 0.001
0.5	0.581	0.22 ± 0.12	-50.33	< 0.001
0.6	0.660	0.23 ± 0.12	-60.45	< 0.001
0.7	0.707	0.24 ± 0.12	-69.60	< 0.001
0.8	0.754	0.24 ± 0.10	-86.65	< 0.001
0.9	0.770	0.23 ± 0.10	-98.51	< 0.001
1	0.786	0.22 ± 0.09	-107.61	< 0.001

Figure S1. Success rate (prey taken per time step) for Q0 (left panels) and Q1 (right panels) foragers in the model, as a function of *PopQ* (x-axes) and the conspicuousness of prey type 2, K_2 (colours). Each row shows the data for a different group size, N.

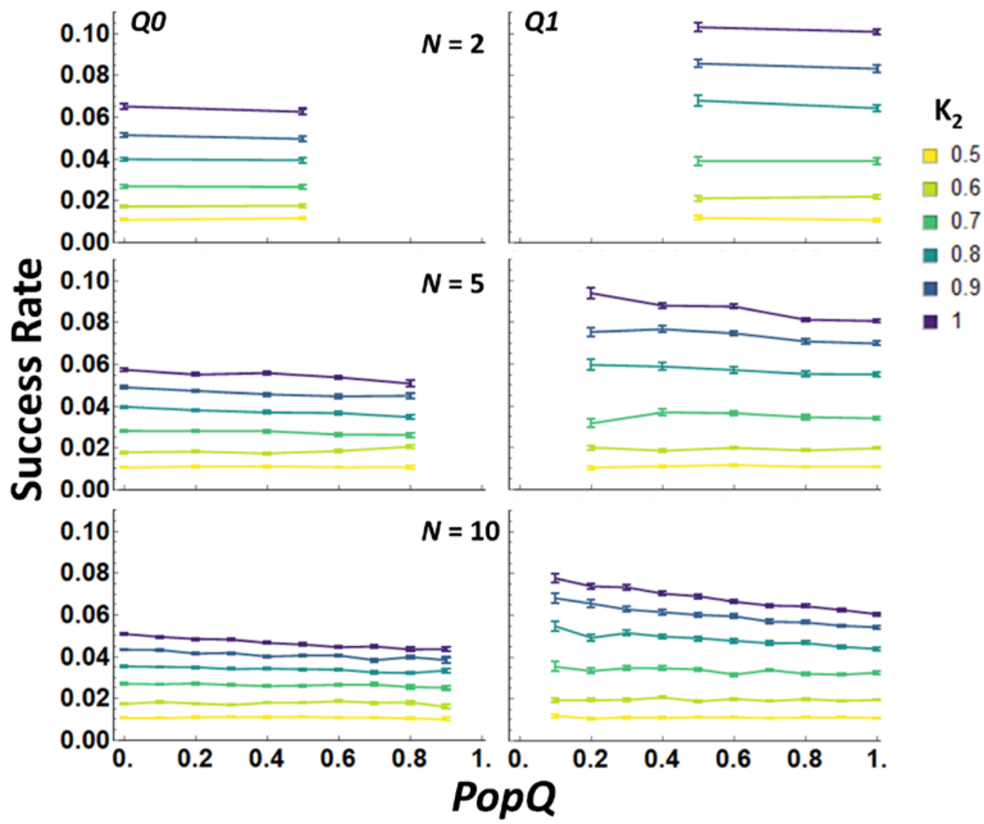

Figure S2. Proportion of prey taken that are of type 2, for Q0 (left panels) and Q1 (right panels) foragers in the model, as a function of *PopQ* (x-axes) and the conspicuousness of prey type 2, K_2 (colours). Each row shows the data for a different group size, N.

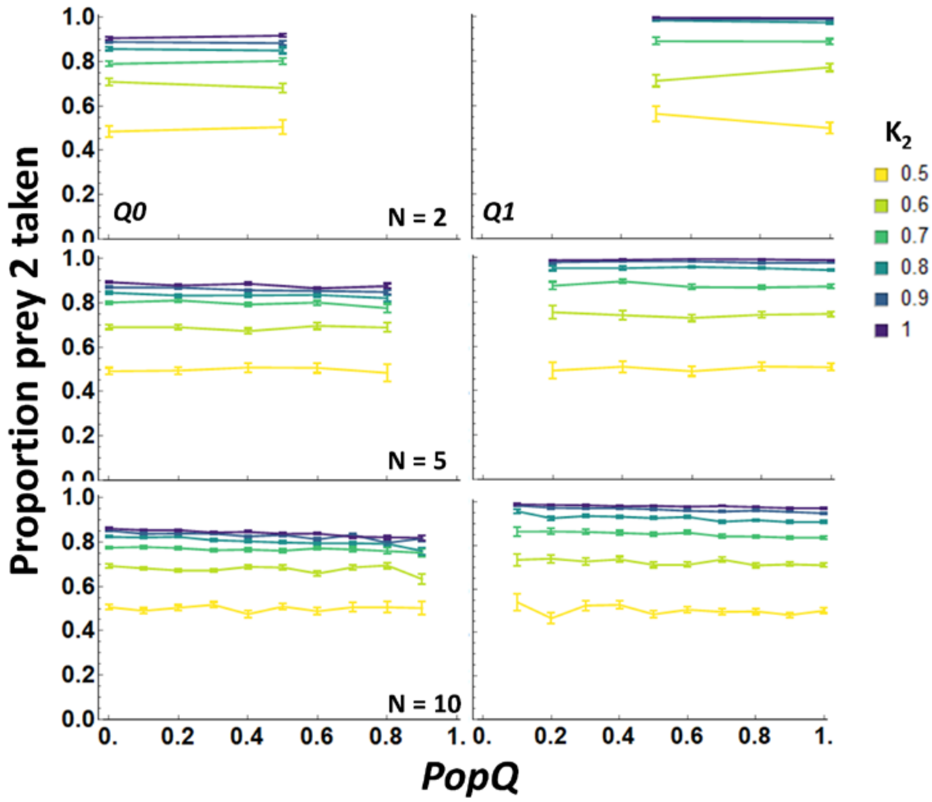

Figure S3. Mean distance in attention-space (Z), for Q0 (left panels) and Q1 (right panels) foragers in the model, as a function of *PopQ* (x-axes) and the conspicuousness of prey type 2, K_2 (colours). Each row shows the data for a different group size, N.

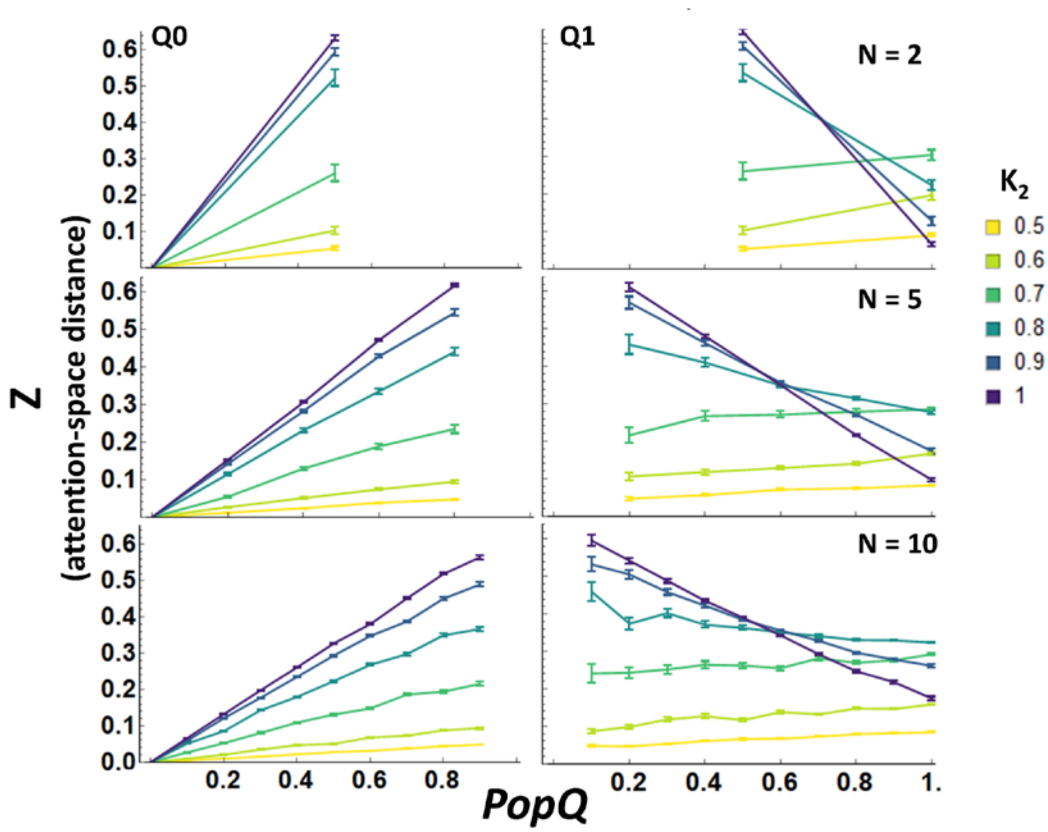

Figure S4. The mean attention level paid to each prey type as a function of *PopQ* (x-axes) and the number of prey types (*M*; different subplots). Data are averaged over all conspicuousness values (K_2). Note the different y-axis ranges in the separate subplots. Colors indicate prey types. Error bars show ± SEM. As the number of prey types increases, attention to each type is diluted.

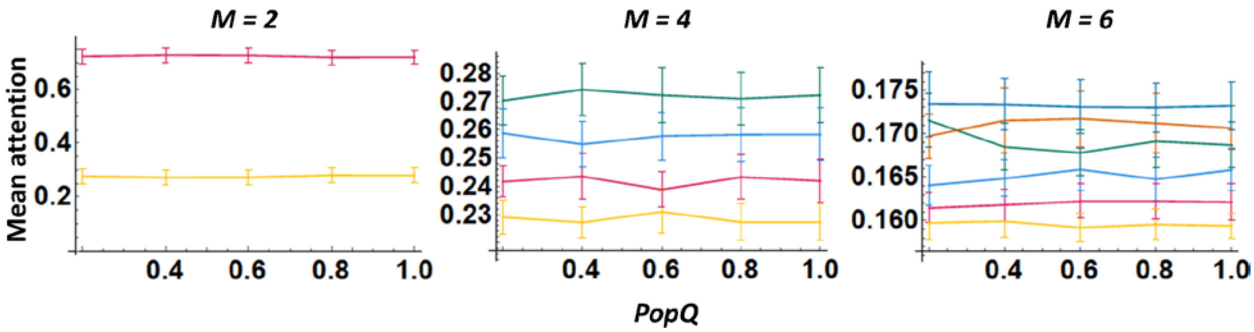

Figure S5. The mean range over which attention varies (within a simulation) as a function of *PopQ* (x-axes) and group size (N; top panel) or number of prey types (*M*; bottom panel). Changing N has no effect on attention range, but increasing *M* reduces agents' ability to focus on a single prey type, reducing the range over which their attention varies. Error bars show ± SEM.

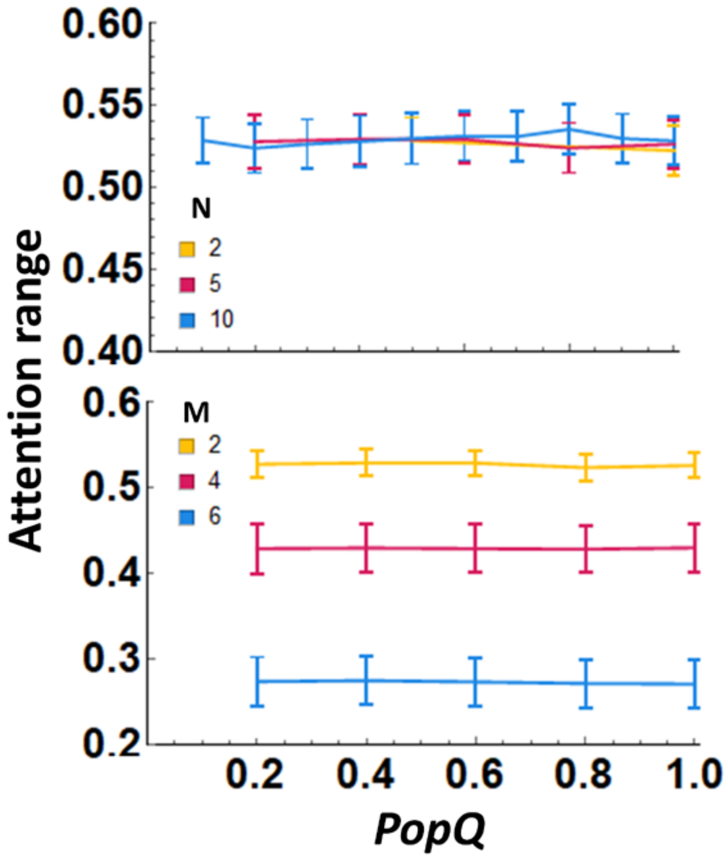

Figure S6. Values of the maximal possible mean distance in attention space (Z*) as a function of group size (N; x-axes), the number of prey types (*M*; lines), and the proportion of the group that can modulate their attention (*PopQ*; top panel, *PopQ* = 1, bottom panel, *PopQ* = 0.5).