Supplementary Materials

Methods

Subjects

Our study population of 20 pinyon jays (*Gymnorhinus cyanocephalus*) were wild born and locally housed. Researchers captured these birds in either Arizona or California (United States Fish and Wildlife permit MB694205) between 2006 and 2011. At capture, they were estimated to be between one and three years of age. The colony has an age range of $10 - 19$ years with a mean of 12.90 years.

The University of Nebraska-Lincoln Institutional Animal Care and Use Committee approved this project (protocol number 1867 and 2059), and all procedures conformed to the ASAB/ABS Guidelines for the use of animals in research. All subjects have completed prior cognitive and behavioral experiments in their tenure with the lab. The colony is handled by humans extensively.

Food Experiment

Apparatus

The apparatus for the food experiment included a bird cage ($72 \times 48 \times 48$ cm) abutting a plastic stand with sliding trays that contained mealworms (Figure S1). The stand was set at a 15 degree angle tilted toward the subject to facilitate mealworm viewing. The stand had two channels the same width as the plexiglas trays. Each plexiglas tray had a standard petri dish placed half an inch away from the front of each tray. Mealworms were placed in the front two thirds of the petri dish so the subjects could easily reach the mealworms, and they were evenly distributed across the available area. Within the cage were three perches. One large free-standing perch stood in the middle of the cage, while two small perches attached to each side of the cage a few inches back from the front. Subjects started each trial perched on the large free standing perch, and they chose an option by landing on the smaller left or right perches. They then consumed the mealworms associated with their decision while the unchosen side was removed immediately.

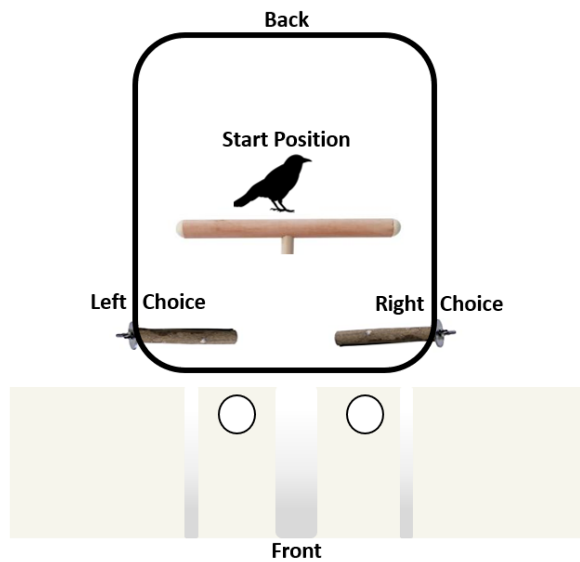

Figure S1: Food experiment apparatus (overhead view)

Habituation and Training

Prior to experimental sessions, all birds were habituated to the experimental room, cage, and stand and then experience training. Depending on the bird this took between 9-16 weeks, as each bird was ran once a day between 11:00-15:00 CST. Subjects experienced four training phases in total; each aimed at teaching the bird a different piece of the paradigm. The first phase (rear cup habituation) habituated subjects to the apparatus. The second phase (front dish habituation) encouraged the birds to place their heads through holes at the front of the cage to consume mealworms from the dishes on the trays. The third phase (moving dish training) introduced the subjects to the fact that the dish on the unchosen side moved out of reach. The fourth phase (mixed reward training) taught the subjects to quickly make a choice between zero or three mealworms, eat, and then set up for another trial in quick succession.

For rear cup habituation, the experimenter brought a subject from their home cage and released them into the test cage. Five mealworms were placed in each of the two feeding bowls into slots at the back of the cage. After three minutes, the experimenter counted the number of mealworms consumed in each food dish and returned the subject to its home cage.

For front dish habituation, the experimenter brought a subject from their home cage into the test cage. Three mealworms were placed in both dishes on the Plexiglass trays. The experimenter pushed the trays forward to present the dishes to the subject in one swift and smooth motion. After three minutes, the experimenter counted the number of mealworms eaten in each dish and returned the subject to their home cage.

Moving dish training was identical to front dish habituation, except the experimenter pulled back the tray in front of the unchosen perch. If subjects ate all three mealworms before three minutes expired, we repeated this process. If the bird did not finish their mealworms we waited the rest of the three minutes before returning them to their home cage.

The mixed reward training was identical to the moving dish training, except one of the dishes held no mealworms while the other held three mealworms and subjects completed six of these 30-second trials per session.

Subjects progressed to a new phase when they successfully consumed at least 70% of the mealworms offered in their current phase for three consecutive days. Subjects could also move to a previous phase if they consumed less than 25% of the mealworms offered on five out of seven days of training.

Procedure

All experimental sessions ran between 11:00-15:00. The subjects were not on a restricted diet. Subjects were fed for the day directly after completing their respective test trials for the day. One experimenter conducted each session. The first trial of the session consisted of one round of mixed reward training. If they failed this check, the experimenter completed two more rounds of mixed reward training. If they failed two out of three of these trials this triggered de-bias training. If they succeed, they continued to the experimental trials. For these trials, the experimenter placed the appropriate number of mealworms in each of the dishes, with mealworms placed 2.5 cm away from each other. The subject then started the trial on the back perch and hopped forward to one of the front perches to signal choice. The experimenter then removed the opposite dish and the subject had up to three minutes to consume their mealworms. If the subject did not make a choice and/or finish all mealworms within three minutes, we ended the session. Once the subject consumed all mealworms, we immediately started the next trial. The first trial of the day where the subject did not finish all their chosen mealworms triggered a stop on that day's session. Subjects completed on average 3.07 trials per session and one session per day. Subjects ran in a randomized order each day.

Side-Bias Protocol

During habituation, three consecutive days of no choices and/or no eating of mealworms on one particular side triggered side de-bias training. During experimental sessions, there were two triggers for de-bias training: either not completing the first 0 vs. 3 practice test trial correctly or when a bird chose the same side for 10 consecutive trials. De-biasing training consisted of three mealworms placed in the dish the subject avoided and no mealworms in the side they preferred. The subject was allowed up to one minute to select the dish that contained mealworms. If the bird did not make a choice or eat any mealworms in the allotted time, we slide both trays all the way out of the stand, placed them out of view of the bird, waited a few seconds, then began the trial over. If they ate within the minute, we reset as soon as they ate until they had five total opportunities to eat. The bird returned to habituation or experimental sessions once they successfully chose the avoided side immediately and ate at least 60% of the mealworms provided.

Social Experiment

Apparatus

The apparatus (Figure S2) was a Y-maze formed out of chicken wire, plastic sheets, and Plexiglas. **Please give dimensions** The subject entered a large chamber at the base of the maze before choosing one of two arms of the Y-maze. At the entrance to both arms, a guillotine style door was closed after the bird walked or flew past it, thus making a choice between the option on the left or right. At the end of each arm, was a large bird cage (72 × 48 × 48 cm) housing the stooge birds. Each cage had two lengthwise perches for the stooge birds to use and one small perch hanging from the ceiling.

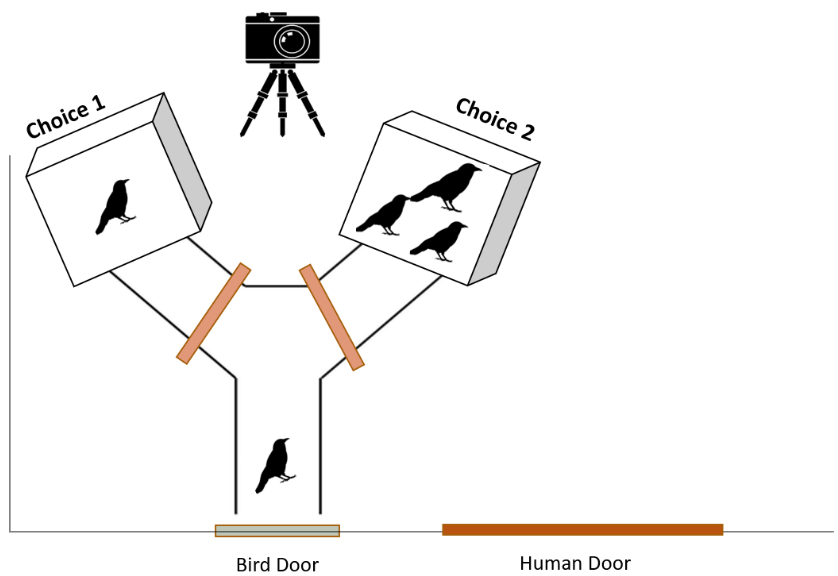

Figure S2: Social experiment apparatus (overhead view)

Habitutation and Training

Prior to experimentation, we habituated all birds to both the experimental room and the apparatus. For habituation, we attached a stainless steal cup to the front of each bird cage.

For a habituation session, the experimenter placed five mealworms in each of the cups. The experimenter then brought the subject into the room, pulled up both doors, and showed the subject each arm of the maze for six seconds, randomizing between subjects the side shown first. The subject was then gently placed on the bottom of the testing chamber as close to the center as possible with the bird facing away from their options. Once the subject crossed the threshold of a door, the door was quietly and swiftly closed behind them and the bird explored the chosen arm and consumed the mealworms for two minutes. After the two minutes expired, the experimenter removed the subject from the apparatus and recorded the number of mealworms consumed.

Subjects experienced 1 habituation session per day for five days a week. They completed habituation once they consistently consumed at least 80% of the mealworms offered to them in both arms of the apparatus and had no significant signs of a side bias. Depending on the bird, this took between 4-6 weeks.

Procedure

All experimental trials ran between 09:00-17:00 CST, with birds being run once or twice a day depending on personnel. The subjects were not food restricted. During replicate 1, two experimenters were present at each session: the 'handler' handled the subject, while the 'recorder' handled the camera, whiteboard, and the guillotine doors. The experimenter placed stooge birds in their respective cages and allowed them to acclimate to the room for 10 minutes before experimentation. The handler then placed the subject inside the apparatus and showed them each option for six seconds (counter balancing which was shown first) before releasing the subject into the chamber. Once the subject crossed the threshold of one of the doors, the recorder closed *both* doors gently but swiftly. After three minutes elapsed, the handler collected the subject and returned them to their home cage. These steps repeated until all birds had run through the experiment. During replicate 2, the recorder's duties were absorbed into the experimenter and the guillotine doors were held open by hooks on the wall to allow the experiment to run smoothly with only one person.

Replicate 1: Each subject experienced 5 repetitions for each of the 21 numerical pairs between 0 and 6 (e.g., 6 vs 5, 6 vs 4, 6 vs 3, etc.). The side of the larger option was pseudo randomized with no left or right runs longer than 3 in a row. The pairs were organized into blocks with one instance of each pair per block and pairs randomized within each block. The order in which the subjects ran in a particular day was also randomized. Only the 15 numerical pairs between 1 and 6 were analyzed. Subjects experience one trial per session and one session per day. Subjects ran in a randomized order each day.

Replicate 2: Each bird experienced 10 repetitions for each of the following 17 numerical pairs between 1 and 6 except for the four pairs that required more than eight stooge birds (4/5, 3/6, 4/6, 5/6). This was done in an effort to better account for individual bird preference among the subjects for certain stooge birds. Randomization was the same for both replicates.

Subjects experience one trial per session and one to two sessions per day. Subjects ran in a randomized order each day.

Side-Bias Protocol

If any subject chose either the left or right side for six consecutive sessions in either habituation or experimentation, they experienced side de-biasing. For side de-biasing, only one door was open in the apparatus, the door leading to the side the subject avoided. We placed five mealworms in the food cup at the end of that arm with no stooge birds present. The bird had up to five minutes to walk/fly past the door into the correct side and three minutes once the door shut behind them to eat the mealworms. Subjects experienced five consecutive trials in a de-biasing session. The subject returned to habituation or experimental sessions once they successfully choose the avoided side immediately upon release and ate at least 60% of the mealworms provided.

Data Analysis

Data were analyzed and processed for the project using R (Version 4.2.1; R Core Team 2022) and the R-packages *BayesFactor* (Version 0.9.12.4.4; Morey and Rouder 2018), *bayestestR* (Version 0.13.0; Makowski, Ben-Shachar, and Lüdecke 2019), *ggcorrplot* (Version 0.1.3; Kassambara 2019), *here* (Version 1.0.1; Müller 2020), *kableExtra* (Version 1.3.4; Zhu 2021), *knitr* (Version 1.40; Xie 2015), *lme4* (Version 1.1.30; Bates et al. 2015), *papaja* (Version 0.1.1; Aust and Barth 2020), *patchwork* (Version 1.1.2; Pedersen 2020), *performance* (Version 0.9.2; Lüdecke et al. 2021), and *tidyverse* (Version 1.3.2; Wickham et al. 2019).

Prior to analysis, we transformed the left and right choice variable from each trial into a binary outcome, with 1 representing a choice for the larger option and 0 representing a choice for the smaller option. We also created variables with the numerical difference between each number pair by subtracting the larger number from the smaller ($6 - 1 = 5$), as well as creating the ratio by dividing the smaller by the larger number ($1/6 = 0.16$). Our hypotheses explore the relationship between our binary outcome variable, choice of the larger or smaller stimuli, and which possible mechanism, difference or ratio, subjects use to make choices when presented with either food or social items.

Our first hypothesis investigated whether pinyon jays prefer larger over smaller numbers of food items and conspecifics. To test this, we conducted a one sample t-test of preference for larger numbers. Therefore, we calculated the mean *percent preference for larger numbers* for each subject and used the t-test to compare the subject means to 50. We perform both frequentist and Bayesian t-tests, with inferences based on Bayes factors. Bayes factors for t-tests were calculated using the `ttestBF` function from the *BayesFactor* R package (Morey et al. 2021) using default, noninformative priors.

Our second hypothesis investigated whether numerical difference and ratio predict preferences between smaller and larger options and the third hypothesis investigated whether difference and ratio predicted preferences *independently*. To test these hypotheses, we used generalized linear mixed-effects modeling as the response variable was dichotomous and our subjects repeatedly made decision on the same number pairs. We used the trial-level choices for either the larger (coded as 1) or smaller (coded as 0) option available in the number pair as the response variable. To investigate our hypotheses, we used generalized logistic models to compare which combination of random (subject, pair, or both) and fixed (ratio, difference, or a combination of both) effects best describe each data set (food and social). We first found the best-fitting random effect structure, then added this random structure to all of the possible fixed effect structures, leaving us with the final best fitting model for each data set overall.

To explore random effect structure, we included models with no fixed effect and either (1) no random effects (intercept only), (2) subject as a random effect, (3) number pair as a random effect (to account for each bird repeatedly seeing each pair multiple times), and (4) both subject and number pair as random effects. For example, the model with both subject and pair as random effects ran using the `glmer()` function with the following structure: `glmer(choice ~ (1|subject)+ (1|pair), family = binomial)` (Table S3 a). We then used Bayes factors to select the model with the best-fitting random effect structure. We added the chosen random effect structure to our fixed effects to find the best-fitting model for the data set overall. The five fixed effects models were: (1) no fixed effects (intercept only), (2) ratio as a fixed effect, (3) difference as a fixed effect, (4) both difference and ratio as a fixed effects but *without* an interaction, and (5) both difference and ratio as fixed effects *with* an interaction. The model with both difference and ratio as fixed effects with an interaction term ran using the `glm()` function and the following structure: `glm(choice ~ difference * ratio, family = binomial)` (Table S3 b). We calculated Bayes factors using the `test_performance()` function from the *performance* package ("Performance: Assessment of Regression Models Performance" 2021), which estimates Bayes factors from model BIC values using Wagenmakers' (Wagenmakers 2007) equation. The best fitting model has the highest Bayes factor.

The second hypothesis can be partially, fully, or unsupported depending on the amount of evidence for or against the ratio only or difference only models. For example, if the Bayes factor for the ratio only model has at least moderate evidence our hypothesis that pinyon jays prefer more items when the quantities have higher numerical ratios is supported. If the difference only model has no evidence supporting it than our second hypothesis would be partially supported.

The third hypothesis can be supported or unsupported based on the outcome of the `difference * ratio` interaction model. If pinyon jays choose items of different ratios and differences independently of each other than you would expect no evidence in support of the interaction model. Evidence in support of the interaction model would signify that choices of mealworms for the same ratio would vary based on the difference and visa versa.

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Supplementary Tables

Table S1: Subject bird information

Subject	Sex	Age (years)	Food 1	Food 2	Social 1	Social 2
Uno	Female	12	X			X
Dumbledore	Male	10	X			X
Fern	Male	11	X			X
Fozzie	Male	15	X			X
He-man	Male	12	X			X
Mork	Male	12	X			X
Mote	Male	12	X			X
Prudence	Male	14	X			X
Saffron	Female	11		X		
Dartagnan	Male	10		X		X
Dill	Male	14		X	X	
Rooster	Male	12		X	X	
Flute	Female	15			X	
Hippolyta	Female	15			X	
Juniper	Female	12			X	
Robin	Female	14			X	
Basil	Male	14			X	
Black Elk	Male	15			X	
Chicklet	Male	10			X	
Juan	Male	12			X	
Mulder	Male	19				X

Table S2: Factorial pair combinations

Pair	Ratio	Difference
1/2*	0.50	1
1/3*	0.33	2
1/4*	0.25	3
1/5*	0.20	4
1/6*	0.17	5
2/3*	0.67	1
2/4*	0.50	2
2/5*	0.40	3
2/6*	0.33	4
3/4*	0.75	1
3/5*	0.60	2
3/6	0.50	3
4/5	0.80	1
4/6	0.67	2
5/6	0.83	1

* The 11 pairs used in replicate 2 of the social experiment.

Table S3: Random and fixed effect model structures tested

(a) Random effects

Model	Formula
Intercept Only Model	`Choice~1`
Subject Only Model	`Choice~(1|Subject)`
Pair Only Model	`Choice~(1|Pair)`
Both Subject and Pair	`Choice~(1|Subject)+(1|Pair)`

(b) Fixed effects

Model	Formula
Intercept Only Model	`Choice~1`
Ratio Only Model	`Choice~Ratio`
Difference Only Model	`Choice~Difference`
Both Fixed Effects, No Interaction	`Choice~Ratio+Difference`
Both Fixed Effects, With Interaction	`Choice~Ratio*Difference`

Table S4: AIC, BIC, and Bayes factor values per model for the food experiment

(a) Replicate 1 random effects

Model	AIC	BIC	BF
`1`	1609.65	1614.74	1.00
`(1|Subject)`	1608.36	1618.54	0.15
`(1|Pair)`	1606.90	1617.08	0.31
`(1|Subject) + (1|Pair)`	1605.17	1620.44	0.06

(b) Replicate 1 fixed effects

Model	AIC	BIC	BF
`intercept only`	1609.65	1614.74	1.00
`ratio`	1589.49	1599.67	1874.16
`difference`	1592.30	1602.48	459.68
`difference + ratio`	1590.90	1606.17	72.38
`difference * ratio`	1592.68	1613.04	2.34

(c) Replicate 2 random effects

Model	AIC	BIC	BF
`1`	753.54	757.88	1.00
`(1|Subject)`	755.54	764.22	0.04
`(1|Pair)`	755.17	763.85	0.05
`(1|Subject) + (1|Pair)`	757.17	770.19	0.00

(d) Replicate 2 fixed effects

Model	AIC	BIC	BF
`intercept only`	753.54	757.88	1.00
`ratio`	746.53	755.21	3.79
`difference`	751.16	759.85	0.37
`difference + ratio`	747.76	760.79	0.23
`difference * ratio`	748.62	765.98	0.02

Table S5: AIC, BIC, and Bayes factor values per model for the social experiment

(a) Replicate 1 random effects

Model	AIC	BIC	BF
`1`	1033.17	1037.79	1.00
`(1|Subject)`	1035.17	1044.41	0.04
`(1|Pair)`	1030.86	1040.10	0.32
`(1|Subject) + (1|Pair)`	1032.86	1046.72	0.01

(b) Replicate 1 fixed effects

Model	AIC	BIC	BF
`intercept only`	1033.17	1037.79	1.00
`ratio`	1033.74	1042.98	0.07
`difference`	1031.68	1040.92	0.21
`difference + ratio`	1033.13	1046.99	0.01
`difference * ratio`	1034.09	1052.57	0.00

(c) Replicate 2 random effects

Model	AIC	BIC	BF
`1`	1524.14	1529.14	1.00
`(1|Subject)`	1526.14	1536.14	0.03
`(1|Pair)`	1526.14	1536.14	0.03
`(1|Subject) + (1|Pair)`	1528.14	1543.14	0.00

(d) Replicate 2 fixed effects

Model	AIC	BIC	BF
`intercept only`	1524.14	1529.14	1.00
`ratio`	1524.87	1534.88	0.06
`difference`	1525.60	1535.60	0.04
`difference + ratio`	1526.67	1541.68	0.00
`difference * ratio`	1528.65	1548.66	0.00

Table S6: Choice for individual stooge conspecifics

Stooge	Number of trials	Female choice %	Male choice %	Overall choice %
Experiment 1				
Males				
Zappa	400	43.1	44.2	43.8
Cash	350	46.4	45.7	46.0
Quince	206	44.3	48.3	46.6
Pease	131	43.3	53.5	48.9
Hagrid	179	46.9	51.3	49.7
Mulder	570	54.4	55.0	54.7
Egeus	600	57.9	53.1	55.0
Sebastian	454	58.5	56.8	57.5
Ariel	406	57.9	59.5	58.9
Females				
Saffron	350	40.0	42.9	41.7
Hermia	134	39.6	45.3	43.3
Scully	163	62.5	47.7	52.8
Mork	630	56.0	55.3	55.6
Comanche	21	62.5	40.0	57.1
Sapphire	56	64.3	78.6	71.4
Experiment 2				
Males				
Cash	770	45.5	48.5	48.2
Pease	818	52.4	49.2	49.5
Hippolyta	818	43.9	50.8	50.1
Zappa	790	58.2	50.6	51.4
Chicklet	828	57.8	50.7	51.4
Females				
Egeus	828	42.2	50.3	49.5
Quince	848	45.9	50.6	50.1
Sapphire	888	57.3	51.4	52.0