PREPRINT

Phantom decoys cause irrational choice in lizards

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Word count: 3284

Abstract

Choice theory generally predicts that individuals act to maximize their benefits and behave according to simple rationality assumptions. However, the predictions of choice theory are often violated when an additional option is added to a choice set leading to a shift in choice between the original options. While this “decoy effect” has been documented across several animal taxa, it has not been investigated in non-avian reptiles. Here, we examined the phantom decoy effect in foraging decisions in the central bearded dragon (*Pogona vitticeps*). After establishing individual food preferences, we first determined choice indifference between the two most preferred foods by manipulating food quantity and then testing how the addition of an unavailable, asymmetrically dominant phantom decoy influenced subsequent choices. Our results show that the addition of a phantom decoy shifted lizards choice towards the less preferred food option. This study provides the first test of contextual decision-making and the phantom decoy effect in a non-avian reptile, offering insight into the evolutionary distribution of irrational choice behaviour.

Keywords: Behavioural economics, Decision-making, Irrational choice, Quality discrimination, Reptile

Introduction

Choice behaviour is often assumed to maximize benefits, follow standard rationality and independence of context [1-2]. Two common assumptions are that the preference ordering between two choices should not be affected by the addition or removal of an option (Luce's choice axiom) and that irrelevant alternatives such as unavailable options should not affect preference ordering (i.e. independence of irrelevant alternatives, IIA) [3-5]. However, both humans and animals make decisions that violate these assumptions, the "decoy effect" being one of the most well-studied violations of rational choice in humans [6]. A decoy represents an addition to a choice set that is designed to shift preference by affecting the perception of the other alternatives and resulting in the violation of the IIA [6]. For example, the addition of a medium-sized coffee at a price close to a large coffee can shift consumer choice from the small towards the large coffee resulting in more profit for the seller. In this example, the decoy can be obtained and is a "real decoy". A "phantom decoy," by contrast, is an option that, despite being unobtainable (e.g., sold out or out of reach), and therefore, not belonging to the choice set, nevertheless influences individuals' choices [7]. For example, in cats (*Felis catus*), the addition of an asymmetrically dominating phantom decoy (high quality chicken) shifted choice behaviour towards chicken and away from fish [8]. Contrary to real decoys, the use of a phantom decoy allows the study of contextual dependence of choice behaviour without the potential influence of random dilution [9].

In animals, both decoy effects have been found in a wide range of species from capuchin monkeys (*Sapajus spp.*) [10], to cats [8], bats (*Aribeus jamaicensis*) [11], hummingbirds (*Selasphorus rufus*) [9], and frogs (*Engystomops pustulosus*) [12]. However, to date, the decoy effect has not been investigated in any non-avian reptile. Non-avian reptiles are a particularly diverse group (> 12,600 species as of June 2026) [13]. From a comparative perspective, data on the decoy effect from across the vertebrate phylogeny would help improve our understanding of the evolution of cognition and decision-making in this context.

Consequently, the aim of our study was to test for the phantom decoy effect on foraging decisions in the central bearded dragon (*Pogona vitticeps*). Bearded dragons are a medium-sized (maximum snout-vent length: 250 mm) [14], omnivorous lizard species from Australia [15]. They are capable of social learning, inhibitory control and can perceive visual illusions related to food quantity, making them an excellent model species to test contextual decision-making via phantom decoys [16-18]. We first determined individual food preference. Using the most and second most preferred food, we then determined the point of indifference in choice between them by varying the quantity of the second most preferred food. Thereafter, we tested the effect of the addition of a third, superior but unavailable option (phantom decoy consisting of four times the preferred food) on choice of the two original options. Under the decoy effect paradigm, we predicted a departure from the original indifference between the two options [8, 10]. However, the directionality is unclear, as there are theoretical reasons for a phantom decoy to create an attraction effect towards the target (more preferred food) or repulsion effect towards the competitor (less preferred food).

Methods

Animals and captive conditions

Twenty adult, wild-caught and F1 captive-born bearded dragons (15 females and 5 males) participated in this study. Female snout-vent length (SVL) ranged from 190 to 237 mm, and male SVL ranged from 213 to 234 mm. All animals were naïve to behavioural testing.

Lizards were kept individually at Macquarie University Fauna Park in open-top plastic tubs (80 L x 60 W x 63 H cm) with artificial grass as substrate, a circular plastic shelter (22 cm diameter) and a water bowl (12.5 x 10.5 cm) that provided water *ad libitum*. Opposite the shelter and water bowl, a lamp hung above a ceramic tile (50 x 31.5 cm) providing a hot spot for basking and UVB (HPM, MP38, 150 W). A branch for climbing was placed above the tile. This setup provided a thermal gradient between 33°C and 43°C (directly under the heat lamp measured on the surface of the tile). All enclosures were placed on the floor with metal shelfs

93 providing the structure to mount the heat lamps as well as cameras used to film behaviour
94 during the experiments (see below). Males and females were spread out across the shed.
95 Lizards were kept under a 12.5:11.5 h light:dark cycle (06:30 – 19:00 h) and air-conditioning
96 ensured that the room temperature was kept at 30°C. All enclosure furnishings, except for the
97 branch, were replaced and cleaned once a week, and the water was replaced whenever it
98 was dirty.

99 During the course of this study, animals were fed seven days a week. Each individual
100 received 15 g of mixed salad (70% bok choy, choy sum, rocket and chicory, 15% red and
101 white cabbage and 15% carrot sweet potato and butternut squash) after the experimental
102 session of the day. On Monday, we added a quarter of an egg (egg white only), while on
103 Wednesday we added two tablespoons of wet dog food (various brands). In addition, lizards
104 were fed one cricket each day (powdered with calcium and vitamins every second day).
105

106 *Experimental setup, stimuli and general procedure*

107 The experiment was conducted from 11th to 22nd of May between 08:30 and 11:00 h, Monday
108 to Friday and the lizards were rested for the weekend. Lizards were tested within their home
109 enclosure using their familiar food dishes (21.7 cm diameter) to minimise stress [19]. To
110 enable the presentation of stimuli on the food dish, the branch was removed during the
111 experimental trials. All other furnishings remained within the enclosure.

112 As stimuli, we used vegetables already present in the lizards' diet: carrot, sweet potato,
113 butternut squash, white cabbage and greens (rocket, choy sum and bok choy). However, for
114 most of the experiment, we only used carrot, sweet potato, and butternut squash (see food
115 preference test). These vegetables were freshly cut into small, bite-sized pieces each day
116 before the first trial.

117 During a trial, we first placed a video camera on the shelf above the enclosures. Next,
118 we gently placed the lizard under the heat lamp on top of the ceramic tile (if not already on the
119 tile) to ensure that lizards would be at optimal body temperature for foraging and covered them

slowly with their shelter. Then we started the video and placed the food dish with the stimuli already set up (see below) at the opposite, cool end of the enclosure (Figure 1A). Finally, we slowly removed the shelter to expose the animal to the setup (supplementary video M1). All trials lasted 20 minutes. We conducted three trials per day with an inter-trial interval of 10-15 minutes (depending on testing stage). Each lizard was tested in a different, randomised order each trial to avoid order effects.

Food preference test

The food preference test aimed to determine the two most preferred foods for each individual, from six options: carrot, sweet potato, butternut squash, white cabbage, and greens. To this end, a small piece of each was presented in each of six trials. Pieces were set up in a half-moon shape along one side of their food dishes with approximately 3 cm space in between (Figure 1B). This set up ensured that all items could be viewed simultaneously from the lizard's starting position on the ceramic tile. All food items were placed in a random, pre-determined sequence that differed in each trial and for each individual (using the sample function in R) [20]. Each lizard was given six trials, three trials per day across two days. If a lizard did not consume any of the stimuli in four trials or more, it did not move on to the next testing stage (N = 7 lizards; Table 1). A food item was scored as chosen if an individual bit into it. In case of ambiguity as to which two food items were preferred (and used in the next part of the experiment) by an individual, more emphasis was given to the last three trials as we assumed that the lizards' choice behaviour was getting more targeted in later trials.

Indifference test

The indifference test aimed at determining the quantity of the less preferred food at which point lizards showed indifference (equal choice proportion) between the preferred and less preferred food. To this end, we presented a set amount of the preferred food (P) and a varying amount (e.g. 1.25x, 1.5x, 2x, 2.5x, 3x, 4x, Table 1) of the less preferred food (LP) next to each

other on the familiar food dish (Figure 1C). In between, we fixed a transparent Petri dish (5 cm diameter, empty) to the food dish using a small piece of putty (BluTak®) in preparation for the last testing stage (see below). We started out by presenting one piece of P versus two, three, or four pieces of LP on the first testing day (order and side randomised across individuals). From there, we either increased or decreased the amount of the LP until lizards chose indifferently between the two options (for the exact result see Table 1). Thereafter, they moved on to the phantom decoy test. Depending on the lizard this took between 3 to 6 days (9 to 18 trials). The side the P was presented was randomised but counterbalanced to ensure that the P never appeared more than three times in a row on the same side. For one lizard (2009), indifference could not be determined. Therefore, only 12 out of 20 dragons moved on to be tested in the phantom decoy test.

Phantom decoy test

The phantom decoy test aimed to determine if the presence of an unavailable, superior third food option would sway the lizards' choice towards one of the two available options. The phantom decoy test was set up exactly as the indifference test; however, four pieces of the P were presented underneath the Petri dish and could be seen but were inaccessible. To the left and right of the Petri dish, we presented one amount of the P and the amount of the LP that was determined to be equally preferable in the indifference test (Table 1, Figure 1C). Each lizard (N = 12) received six trials of the phantom decoy test across two days. Again, the side the P was presented was randomised but counterbalanced.

Statistical analyses

All analyses were run in R version 4.6.0 [20]. All data generated during this study and the code used for analysis are available for download at the Open Science Framework (OSF, Link for review purposes: https://osf.io/fhp6y/overview?view_only=9c3669632ddd4b9593b97867949aef3d).

174 To determine if the presence of an unavailable superior food option (phantom decoy)
175 shifted the lizards' choice behaviour we compared choice behaviour shown in the indifference
176 test with the behaviour shown in the phantom decoy test. We ran a Binomial Bayesian
177 generalised linear mixed model (GLMM) with the choice (1 = preferred, 0 = less preferred) as
178 the response variable (package *brms*) [21-23]. As fixed effects we included stage
179 (indifference, decoy), sex (male, female) and the scaled mass index (SMI). Animal identity
180 was included as the random intercept while trial nested in session (testing day) was included
181 as the random slope. SMI was included as the measure for body condition and calculated
182 following Peig and Green [24]:

183 $$SMI_i = M_i \left[\frac{L_{av}}{L_i}\right]^{b_{SMA}}$$

184 SMI_i represents the scaled mass index of individual i, M_i and L_i represent the mass and SVL
185 of individual i, respectively. L_{av} represents the average SVL of the study population and b_{SMA}
186 the scaling exponent estimated by a standard major axis regression of mass on SVL (package
187 *smart*) [25].

188 We ensured that model Rhat was 1, that the ESS was above 2000 and checked the
189 density plots and correlation plots to ensure that the models had sampled appropriately. We
190 used a non-informative prior (see provided R code for details) and ran four chains per model
191 of 5000 iterations each and a thinning interval of 1 (default settings). We used Bayes factors
192 (BF) to evaluate the inclusion of predictors by determining BF from marginal likelihoods using
193 the package *brms*. In accordance with Schmalz and colleagues [26], we report results as
194 follows: BF above 1 but below 3 are reported as a weak support for inclusion, BF larger than
195 3 but below 10 are reported as support for inclusion, BF larger than 10 but below 30 are
196 reported as strong support for inclusion, and values larger than 30 are reported as very strong
197 support for inclusion. We determined the significance of predictors by looking at the credible
198 interval. If the credible interval did not cross 0, a predictor was deemed significant.
199

Results

All 12 lizards changed their choice behaviour when a phantom decoy was present. Nine showed a repulsion effect, that is, they shifted their choice towards the less preferred food, while three showed an attraction effect shifting their choice towards the preferred food (Figure 2). This was supported by the results of our analysis indicating that, overall, lizards increased their choices towards the less preferred food (GLMM, $estimate_{equilibrium}$ = 1.114, CI_{lower} = 0.230, CI_{upper} = 2.230; Figure 2). Model comparison strongly supported the inclusion of stage in the model (BF = 22.722).

Neither sex nor body condition (SMI) predicted choice behaviour (sex: GLMM, $estimate_{male}$ = 0.266, CI_{lower} = -1.401, CI_{upper} = 1.918; SMI: GLMM, estimate = -0.007, CI_{lower} = -0.029, CI_{upper} = 0.017). Model comparison did not support the exclusion of SMI in the model (BF = 0.034) but weakly supported the inclusion of sex (BF = 2.044).

Discussion

Our results confirm our prediction that the addition of an asymmetrically dominant phantom decoy would sway choice behaviour [27]. The majority of lizards (9/12, 75%) that were tested in our study shifted their choice from indifference between the two presented options towards choosing the competitor (less preferred food) over the target (preferred food). However, three lizards did shift their choice in the opposite direction, towards the target. This shows that, even in lizards, irrelevant alternatives are not independent and affect decision-making even when choice alternatives are unavailable.

In our study, we used a superior yet unavailable alternative as the phantom decoy [27]. There are theoretical reasons for a phantom decoy to create an attraction effect towards the target (more preferred food) or repulsion effect towards the competitor (less preferred food). Theories predicting an attraction effect include similarity substitution, scarcity attractiveness, and range weighting, whereas a repulsion effect is predicted by reactance theory, range frequency, and the dimensional valuation model [8, 28]. Further, both effects have been found

227 depending on whether the phantom is known or unknown, its' distance to the target, and
228 whether it is used in a perception task or preference task [28-30]. Here, our findings of a
229 repulsion effect in most bearded dragons is best explained by reactance theory. Within this
230 framework, the phantom decoy is perceived as forcing a choice towards the target (preferred
231 food), and therefore, restricting freedom. This constraint results in a boomerang effect with
232 choices directed towards the competitor rather than the target [31]. This effect is predicted to
233 be even stronger when the unavailability of the phantom is unknown, such as in our study in
234 which all individuals attempted to consume the phantom decoy during trials [28, 31]. However,
235 not all lizards showed this shift towards the competitor but rather towards the target. This might
236 be explained by the principle of similarity substitution. As the decoy decreases in similarity to
237 the target (i.e. becomes more dissimilar to the target in one dimension) the weaker its effect
238 [28]. In our case, we chose a distant phantom, a disproportionately larger amount of the
239 preferred food (four times as much). Nevertheless, our results suggest individual differences
240 in attention and cognitive processing that should be the focus of future studies.

241 Another interesting finding is that bearded dragons were able to equate the quality and
242 quantity of food. The results of our indifference test show that providing a larger quantity of
243 less preferred food can shift preference away from the more preferred food. Although a range
244 of reptiles have shown the ability to distinguish quantity [32-36], to the best of our knowledge,
245 this is the first study demonstrating that quantity can override quality in bearded dragons. An
246 ability to trade-off quality for quantity could be important under natural conditions. For
247 example, grey whales (*Eschrichtius robustus*) fed on a lower calorie but more abundant mysid
248 species, rather than on a more calorie rich species at a non-profitable density [37]. The whales'
249 behaviour suggests optimisation of foraging decisions dependent on prey availability. Some
250 studies in lizards demonstrated nutrient need sensitive foraging choices such as in the desert-
251 dwelling lizard *Saara hardwickii*, that shifts prey choice based on seasonal need. Despite
252 insects being abundant all year round, they are only consumed during the breeding season
253 [38]. Therefore, being able to shift choices between low-quality abundant and high-quality low
254 abundant resources could similarly be adaptive in desert-dwelling central bearded dragons.

Together, our results show that phantom decoys affect lizards' choice similar to what was found in other vertebrates [8-9, 10-12]. However, the current literature on the decoy effect and irrational choice in animals is still small [39]. Therefore, further studies on a broader range of species are needed to better understand the underlying mechanism involved.

Acknowledgements

Our colony was generously provided by Arthur Georges and Sarah Whiteley (University of Canberra). We thank the Macquarie University MARS team for excellent husbandry support.

Funding statement

This research was funded by Ghent University (Seed funding to BS; Methusalem Project: 01M00221 to FV).

Author contribution

BS, MJW - Conceptualization; BS - Data curation; BS - Formal analysis; BS, MJW - Funding acquisition; BS, RB - Investigation; BS - Methodology; BS, FV, MJW - Project administration; BS, MJW - Resources; BS, RB - Validation; BS - Visualization; BS, RB, FV, SCG, MJW - Roles/Writing - original draft; BS, RB, FV, SCG, MJW - Writing - review & editing.

Declaration of AI use

ChatGPT was used to assist in the creation of the abstract. All ChatGPT output was carefully evaluated and revised by the authors. No AI was used to create or modify any other sections of the paper.

Conflict of interest

We declare no conflict of interest.

Ethical statement

All tests were strictly non-invasive and followed the guidelines provided by the Association for the Study of Animal Behaviour/ Animal Behaviour Society for the treatment of animals in behavioural research and Teaching [40]. Experiments were approved by Macquarie University animal ethics committee (ARA 2026/009) where experiments took place.

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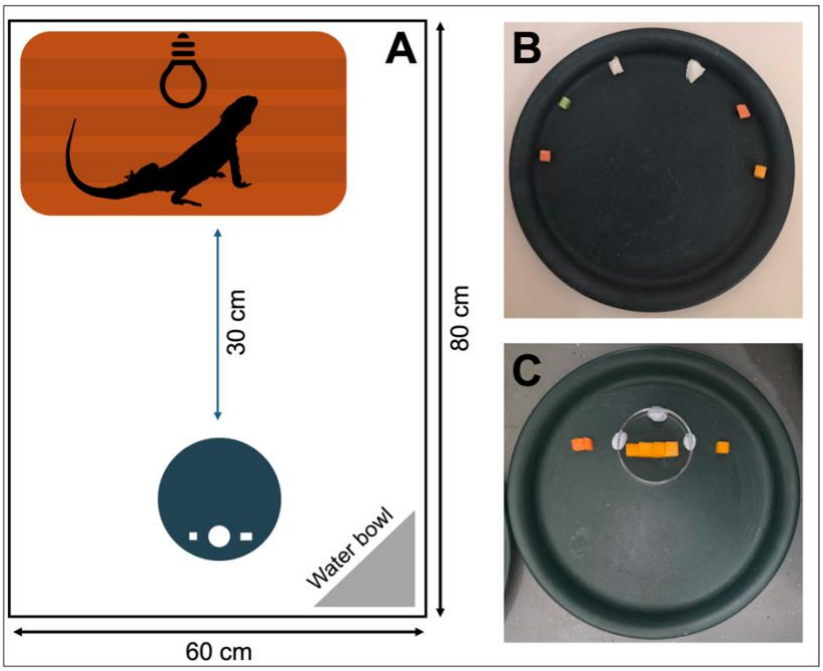
Table 1. First three choices across the six preference test trials for each individual. The two vegetables used in both the indifference test and decoy test are highlighted in bold. – no choice made/ no data. * lizard was first tested with potato and squash, but then switched to carrot and squash because indifferences could not be achieved between potato and squash (but with carrot and squash).

Animal ID	Sex	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Indifference
1950	Female	**Carrot** **Squash** Potato	**Squash** **Carrot** Potato	-	**Squash** Potato **Carrot**	**Squash** **Carrot** Potato	**Squash** **Carrot** Potato	1.75 carrot versus 1 squash
1618	Female	**Squash** **Potato** Carrot	**Squash** **Potato** Greens	**Squash** Carrot Egg	**Squash** **Potato** Egg	**Squash** **Potato** Cabbage	**Squash** **Potato** Egg	2 potato versus 1 squash
2167	Female	Squash Carrot -	-	-	-	-	-	-
2165	Female	-	-	-	-	-	-	-
1497	Female	Carrot Squash Potato	-	-	-	-	-	-
1375	Female	Carrot Squash Egg	Squash Carrot Egg	-	-	-	-	-
1380*	Female	**Potato** **Squash** **Carrot**	**Potato** **Squash** **Carrot**	**Potato** **Squash** **Carrot**	**Potato** **Squash** **Carrot**	-	-	1.5 carrot versus 1 potato
1495	Female	**Squash** **Carrot** Potato	**Squash** **Carrot** Egg	**Squash** Potato Egg	**Squash** **Carrot** Potato	**Squash** **Carrot** Potato	**Squash** **Carrot** Potato	1.5 carrot versus 1 squash
1496	Female	Greens Potato Egg	-	-	**Carrot** **Squash** Potato	Potato **Squash** **Carrot**	**Carrot** **Squash** Potato	3.25 squash versus 1 carrot
1494	Female	**Squash**	**Squash**	**Squash**	**Potato**	**Squash**	**Potato**	3 potato

		Carrot **Potato**	Carrot **Potato**	Carrot **Potato**	**Squash** Cabbage	**Potato** Egg	Carrot **Squash**	versus 1 squash
1500	-	-	-	-	-	-	-	-
1942	Female	Squash -	-	-	Squash -	-	-	-
1372	Female	**Squash** **Potato** Carrot	**Squash** **Potato** Carrot	**Squash** **Potato** Carrot	**Squash** **Potato** Carrot	**Squash** **Potato** Carrot	**Squash** **Potato** Carrot	2 potato versus 1 squash
1704	Female	-	-	-	Squash Greens Carrot	-	-	-
1947	Male	Greens Egg **Squash**	**Squash** **Potato** Carrot	-	**Squash** **Potato** Carrot	**Squash** **Potato** Carrot	**Squash** **Potato** Egg	2 potato versus 1 squash
2009	Male	**Carrot** **Squash** Potato	-	-	**Carrot** **Squash** Potato	**Carrot** **Squash** Potato	**Carrot** Potato **Squash**	-
1948	Male	Potato **Squash** **Carrot**	**Carrot** -	**Squash** -	**Squash** **Carrot** Potato	**Squash** **Carrot** Potato	**Squash** Potato **Carrot**	1.5 carrot versus 1 squash
1367	Male	**Potato** **Squash** Carrot	**Squash** **Potato** Carrot	Carrot **Squash** -	**Potato** **Squash** Carrot	**Potato** **Squash** Carrot	**Potato** **Squash** Carrot	1.5 squash versus 1 potato
1376	Male	**Squash** **Carrot** Potato	**Squash** Potato **Carrot**	**Squash** Potato **Carrot**	**Carrot** **Squash** Potato	**Squash** **Carrot** Potato	**Squash** **Carrot** Potato	1.5 carrot versus 1 squash
1369	Female	**Squash** Carrot **Potato**	**Squash** **Potato** Carrot	**Squash** Carrot -	**Squash** Carrot **Potato**	**Squash** **Potato** Carrot	**Potato** **Squash** Carrot	1.75 potato Versus 1 squash

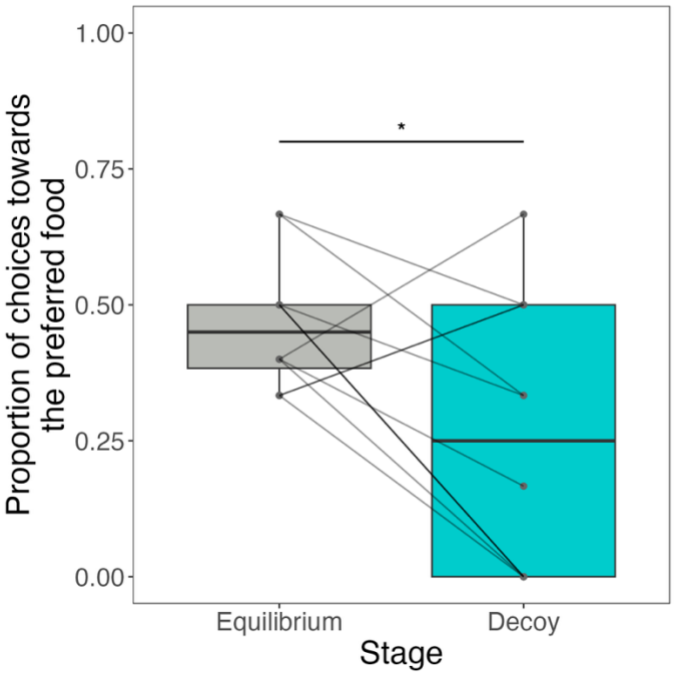
405



406

407 **Figure 1.** A) Schematic representation of the enclosure setup during testing indicating the
408 start position of lizards as well as the position of the food plate used to present the stimuli. B)
409 Setup used during the food preference test. Food from left to right: carrot, green, cabbage,
410 egg, sweet potato, squash. C) Setup used during the decoy test. Depicted are 1.5 times sweet
411 potato on the left and 1 times squash on the right with 4 times squash as the asymmetrically
412 dominating, unobtainable (blocked by a Petri dish) decoy.

413



414

415 **Figure 2.** Boxplot depicting the proportion of choices directed towards the preferred food
416 during the equilibrium test (grey) and the phantom decoy test (turquoise). Points represent
417 individual data and lines connect performance across test stages. The bold line within the
418 boxes shows the median, the upper and lower edges represent the upper and lower quartile,
419 and the top and bottom whisker ends show the maximum and minimum. * significant difference
420 based on credible intervals excluding 0.

421