

Original Article

Food and Food-Odor Preferences in Dogs: A Pilot Study

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Abstract

Evaluation of food palatability and preference is of great importance to the pet food industry. One common technique for evaluating palatability is a 2-bowl test in which 2 products are offered simultaneously and food consumption is measured. This yields clear results with dogs trained to routinely conduct such comparisons, but it is less clear how this extends to untrained pet dogs. In addition, prior research indicates that olfaction is important in food preference, but methods for evaluating odor preference in canines are currently lacking. In this study, we developed a modified 2-bowl test for evaluation of food preferences in pet dogs with minimal training, and an olfactometer technique for the evaluation of odor preferences. In our 2-bowl procedure, we observed clear preferences among 4 commercial food products in 6 pet dogs. Across repeated testing, preferences strengthened, but the first evaluation accurately estimated the direction and significance of preference. In addition, dogs typically (89% of the time) consumed more of the food they chose first, suggesting they did not need to taste each food to choose. Our odor preference olfactometer assessment, however, did not reveal odor preferences other than that dogs preferred to sniff a food odor over clean air. Further work will be needed to identify methods of measuring odor preferences amongst food odors for dogs, but the modified 2-bowl test shows promise for further testing in pet dogs.

Key words: canine, odor, olfaction, preference, palatability

Olfaction and taste combine to produce flavor, which is critical in determining the consumption of a food (Di Lorenzo and Youngentob 2003). In dogs, olfaction is believed to play an integral role in the sensory experience of eating and food choice (Haupt et al. 1978, 1982; Haupt and Smith 1981; Bradshaw 1991, 2006; Horowitz et al. 2013). Little information, however, has been published about what odorants dogs naturally find hedonically appealing and whether such odors enhance palatability and food consumption. This information would aid understanding of the effects of odorants on feeding behavior. Though a number of studies investigating food choice in dogs were published in the 1970s and 1980s (Haupt

et al. 1978, 1982; Haupt and Smith 1981; Chao 1984; Ferrell 1984; Green and Rashotte 1984; Rashotte and Smith 1984; Rashotte et al. 1984; Smith et al. 1984), little work has been published since then, and several important questions remain unresolved.

The main focus in earlier studies was on measuring food consumption and palatability using a variety of operant procedures. In these studies, dogs were provided with 2 levers, both with the same schedule of reinforcement, but either different types (Chao 1984) or quantities of foods (Green and Rashotte 1984). Such procedures proved useful to hedonically scale dogs' preferences between glucose, fructose and sucrose (Chao 1984); however, Rashotte et al. (1984)

found that when 2 foods were offered in a concurrent choice operant task, responding did not always match preference in a 2-bowl test. This suggests that there are likely multiple controlling variables that may differ between a 2-bowl test and an operant choice task.

The 2-bowl test remains the standard procedure for examining food preferences in dogs and cats (Aldrich and Koppel 2015; Tobie et al. 2015). Typically, a panel of dogs is given 2 bowls of slightly differing food containing pre-measured amounts of the diets. The dogs are given free access to the bowls for a given period of time, and the dog's first choice, as well as the food they consume most, are recorded. In several variations of the procedure, the choice can be presented again, but the sides the foods were presented are reversed to control for side biases. In addition, the foods can be placed on scales to electronically record consumption (Smith et al. 1984; Vondran 2013).

Although 2-bowl procedures have been well established in the pet-food industry, it is not clear how well they might extend to evaluations using unselected groups of pet dogs. Prior research has demonstrated correspondence between kenneled and pet dogs in preference between canned foods, but preference differences between the 2 populations were evident in semi-moist and dry food products (Griffin et al. 1984). Other studies, however, have failed to detect food preferences in pet dogs (Smith et al. 1983). Recently, Vondran (2013) evaluated the preferences of dogs in an in-home setting using a proprietary computer based 2-bowl test. Vondran found that their 2-bowl test detected some preferences between dry pet-food products in a group of 25 pet dogs and that the group's overall preferences did not change from the first to the seventh day of presentation.

Additional methods outside of 2-bowl tests have been developed to measure canine food preferences. One method is the cognitive palatability assessment protocol in which a few dogs are trained using objects as stimuli representing different food products (Araujo and Milgram 2004; Araujo et al. 2004). An experimenter then measures dogs' choice between the objects associated with the foods. This procedure is designed to limit food intake and variability amongst dogs, but is associated with a lengthy training phase. Attempting to address similar limitations, another study used dogs' investigation of unobtainable food as a measure of preference (Thompson et al. 2016). Furthermore, other researchers have used paired stimulus assessments of reinforcers to evaluate reinforcer preference (Vicars et al. 2014) or have used a simple hand touch response to measure reinforcer effectiveness between different foods or food and social reinforcers (Feuerbacher and Wynne 2012; Vicars et al. 2014). These procedures, however, have not yet been used to evaluate preferences between different brands or formulations of dog food where preference differences may not be strong.

Few prior studies have focused on evaluating the role of olfaction in food choice for dogs. Dogs' ability to distinguish between foods flavored with different meats requires olfaction (Haupt et al. 1978, 1982). Haupt et al. (1982) rendered trained flavorist dogs (dogs that were trained to distinguish between foods derived from different meat sources) anosmic. This led to a precipitous drop in performance and dogs were no longer able to discriminate the foods above chance levels. In addition, dogs that preferred one meat type to another no longer showed preferences after being rendered anosmic (Haupt et al. 1978). Similar work in mice suggests that olfaction may be critical in preference for higher fat foods (Kinney and Antill 1996). Furthermore, very little is known about what odorants influence palatability in dogs, except for a recent study that correlated the food preference results of 8 dogs with chemical analysis (solid phase

micro-extraction and gas chromatography mass spectrometry) for dog food palatability additives (Chen et al. 2016).

It remains unclear how preferences for odors influence canine food preferences. Prior research indicates that olfaction is critical in discerning between preferred and non-preferred foods, however, it is not clear whether the odors of the preferred foods are themselves more hedonically appealing and therefore support food discrimination, or whether dogs simply use odor stimuli as cues to discriminate one preferred food from another. One potential reason for a lack of research in this area is that methods to measure food odor preferences in dogs are lacking. Although odor discrimination training methods have been extensively studied in canines (e.g. Oxley and Waggoner 2009), there has been less research on measures of odor preferences in non-human animals. Most methods involve measuring place preference near an odor (e.g. Xiao et al. 2004; Thompson et al. 2016), but it remains unclear how long dogs may investigate an odor source over multiple testing conditions of paired comparisons between 2-food odors. Therefore, in this study we develop a procedure that allows the repeated evaluation of a variety of odor preferences in dogs.

The present study has 3 aims. First, we develop a technique to measure individual food preferences in pet dogs. Second, we develop a companion technique to assess the same dogs' preferences for the odors of these foods. Both techniques are designed to be applicable to dogs with minimal training, and repeatable across time. Third, we explored the relationship between the set of preferences for odors of foods and the preferences for consuming the foods themselves. We hypothesized that the hedonic values of the food odors would be associated with canine food consumption.

Methods

Subjects

Six pet dogs were recruited for this study. Six dogs were selected because we were interested in identifying individual level preferences through repeated measures rather than population level preferences. Dogs were tested in a convenient location in owner's homes. The dogs were reported to be in good health, and were able to tolerate being fed different diets. Table 1 gives information on breed and age for each dog.

Food products

Four commercial poultry-flavored dog food products available in North America were utilized throughout the study. The diets were chosen such that we expected to see both clear preferences between some products and no preference between some products. These foods were Old Roy Complete Nutrition, Nutro Natural Choice (Chicken, Whole Brown Rice, and Oatmeal Recipe), Royal Canin Medium Adult, and Purina Dog Chow Complete. These diets were novel to all the dogs. Throughout the study, the foods were coded by

Table 1. Subject information

Subject	Age	Sex	Breed	Food Allowance (g)
Bessa	5	SF	Pit-bull Mix	15
Chaco	7	SF	Australian Cattle Dog Mix	15
Bo	10	NM	Australian Cattle Dog Mix	15
Winnie	1	SF	Shih Tzu Poodle Mix	3
Chewy	5	SF	Chihuahua Mix	3
Meeko	7	NM	Chihuahua Mix	3

their randomly assigned number so that all experimenters and study staff were blind to the identity of the foods.

Apparatuses

Two-bowl apparatus

Figure 1 shows the apparatus. The device was similar to prior devices used (e.g. Vondran 2013) which electronically record consumption of 2 foods. Our device held 2 kitchen scales, which were recessed in 2 circular openings. The scales measured the weight of the foods continuously during each trial. Unlike Vondran (2013), a removable fiberglass screen could be slid above the bowls along a track on the side panels like a drawer. The screen prevented the dogs from accessing the food, but allowed them to see and smell both foods. The scales were connected to an Arduino® Uno micro-controller, which was then connected to a computer that recorded the data.

We assessed scale linearity and converted the analog reading to weights by comparing obtained readings of standard items to a comparison scale (Taylor Model 3839). Accuracy was typically observed to be within ± 1 g. Calibration of the scales was rarely needed. The coefficient of variation values for the calibration coefficients were 1.3% and 0.5% for the left and right scales, respectively.

Odor preference olfactometer

A 2-port olfactometer was designed to present food odorants to the dog and measure preference. The olfactometer had 2 stainless steel odor ports in which the dogs could place their nose. IR beam sensors detected the presence of the dog's nose in the odor port.

The design principle of the olfactometer was similar to that used in Hall et al. (2016). Glass jars with Teflon faced liners held 100 g of a food. Two stainless steel bulkheads provide an inlet and outlet path to the jar. To present an odorant, clean activated carbon and particulate filtered air was pumped into a desired jar containing the desired food product at rate controlled by a flow meter. This air was then blown across the food product, and the headspace volume was pushed through the outlet bulkhead towards the desired odor port. All odor presentations were under computer control through the use of 2- and 3-way solenoid valves. The olfactometer was designed so that odor wetted components were comprised only of Teflon®, glass, or stainless steel (SS 316 grade). All aspects of the experiment were under computer control including odor presentation, food delivery, and data collection.

Procedures

Food preference procedure

Dogs were tested in 1 daily session of 8 trials per day. During each trial, they were allowed to consume 1/8th of a “normal meal” that would occur around the time of testing. To calculate 1/8th of a normal meal, on the first session, owners were asked to provide the experimenter with what they would normally feed their dog for a meal. The experimenter then weighed the food, and divided that quantity by 8 and rounded to the nearest whole number of grams (see Table 1 for values for each dog). This value was then set as the food limit. A trial was considered complete when the dog's total consumption of the foods met or exceeded the food limit.

At the start, the dog was either held back by an owner or placed in a separate room as the experimenter prepared the trial. The experimenter then placed 100 ± 1 g of one food in the left bowl and 100 ± 1 g of the comparison food in the right bowl. The screen to the 2-bowl apparatus was then replaced, preventing the dogs from accessing the food, but allowing them to see and smell the foods available. Once the screen was in place, the experimenter started a 15-s timer and released the dog to explore the 2-food options. At the end of 15 s, the screen was removed, and the dogs were allowed to eat. The computer took weight measurements continuously, but filtered out weight increases from dogs pressing down on the scales while eating, and subjected the remaining samples to a median filter. Due to filtering time, filtered weight measurements were recorded approximately every 700 ms.

Once the computer registered that the dog had consumed its food limit, an indication on the computer screen prompted the experimenter to replace the screen, preventing the dog from eating further. Once the screen was in place, the dog was called back by the owner or placed in a separate room in preparation for the next trial. If the dog did not consume up to the food limit within 15 min, the dog was considered satiated and was not tested further for that day. The next session began the following day.

During a session, all 8 trials were comprised of a single comparison, but the side the foods were placed on was pseudo-randomly determined so that the foods appeared on the left and right side 4 times each during a session. To prepare for the next trial, the computer would indicate which food should be on which scale. The experimenter would then switch the bowls if needed, and add food as needed to bring both foods back to 100 ± 1 g.



Figure 1. Image of dog with 2-bowl apparatus: a box that contains 2 scales on top of which the food bowls are placed. The scales and bowls were recessed in the circular openings. This prevented the bowls from being accidentally moved off the scale while the dog ate. A removable screen could be slid on top to prevent the dog from accessing the food, but allowed it to see and smell the food options.

There were a total of 6 pairwise food comparisons (1 vs. 2, 1 vs. 3, etc.). In addition, we conducted a 7th control comparison, in which the same food (randomly selected from the 4 foods) was presented in both bowls. The same food was first split into 2 bowls, and 1 bowl was labeled as “Control A” whereas the other was labeled “Control B” to distinguish them. The testing session was then run identically to a non-control session. This control was to test whether the dogs would choose to eat one food over another based on unintentional cues, perhaps provided by the experimenter, or odor cues left on bowls from the previous trials. We expected that if these factors were not biasing dogs’ choice, preference during controls should not be significantly different from 50%.

The order of presenting the food comparisons was determined by a random selection procedure without replacement of the 7 possible comparisons (6 pairwise food comparisons and 1 control). This procedure was repeated 4 times so that each comparison was presented for 4 sessions. With 8 trials per session, this yielded a total of 32 trials per comparison for each dog or 224 trials in total. Overall, Bessa, Bo, and Chaco completed all trials, Meeko: 222, Chewy: 207, and Winnie: 170. Non-completed trials were the result of the dog refusing food prior to the completion of all 8 trials in a session.

Odor preference procedure

Training

Dogs were trained in daily 40-trial sessions with vanilla extract and mint extract as odorants. Vanilla and mint were selected for convenience for initial training. A session was only terminated in less than 40 trials if it failed to make any response following 10 min. We used Pet Botanics® treats as a reward for both the training and testing phase.

Dogs were first given “hopper” training in which the feeder was manually activated several times to encourage the dog to approach and investigate the olfactometer. After the trainer running the feeder determined the dog was interested in the olfactometer, a computer controlled shaping procedure was implemented to train the dogs to place their nose in either of the odor ports. At first dogs only needed

to place their nose in the odor port for 0.5 s to receive food. After every successful nose poke, the length of nose poke required for food to be delivered increased by 0.1 s. If no response was recorded for 1 min, the response requirement was decreased by 0.5 s for the next trial and food was delivered immediately for any nose poke made for the ongoing trial. This nose poke training continued until dogs reached a nose poke criterion greater than 3 s.

Following successful nose poke training, dogs were given training on forced trials. In a forced trial, only 1 nose port was active, which was signaled by the presence of an odor (vanilla on the left port or mint on the right port) and a correlated LED light above the odor port (Figure 3). For training, the response requirement clock was re-set to 0.5 s so that only a 0.5 s response on the correct port was required to receive food. Responses on the non-active port had no consequence. The response requirement timer was increased by 0.1 s for every successful response, and decreased by 0.5 s if no appropriate response was made within 1 min. Once the response requirement time reached greater than 3 s (which was based on the dogs making the appropriate response to the active odor port) by the end of a session, dogs were transitioned to the final training session.

During the final training session, dogs were given a testing session (described in detail below) in which the odor presented to the left port was vanilla extract and the odor presented to the right port was mint extract.

Preference testing

Testing sessions were comprised of 40 trials. Each session was composed of forced and free trials in which 2 forced trials followed by 2 free trials were repeated for a total of 40 trials. One food odor was presented to the left port and one food odor was presented to the right port throughout these entire sessions. During forced trials, only 1 port was active and this was signaled by an illuminated LED (Figure 2). Responses to the incorrect side had no consequences. During each block of forced trials, 1 trial forced the dog to sample the odor in the right port and the other

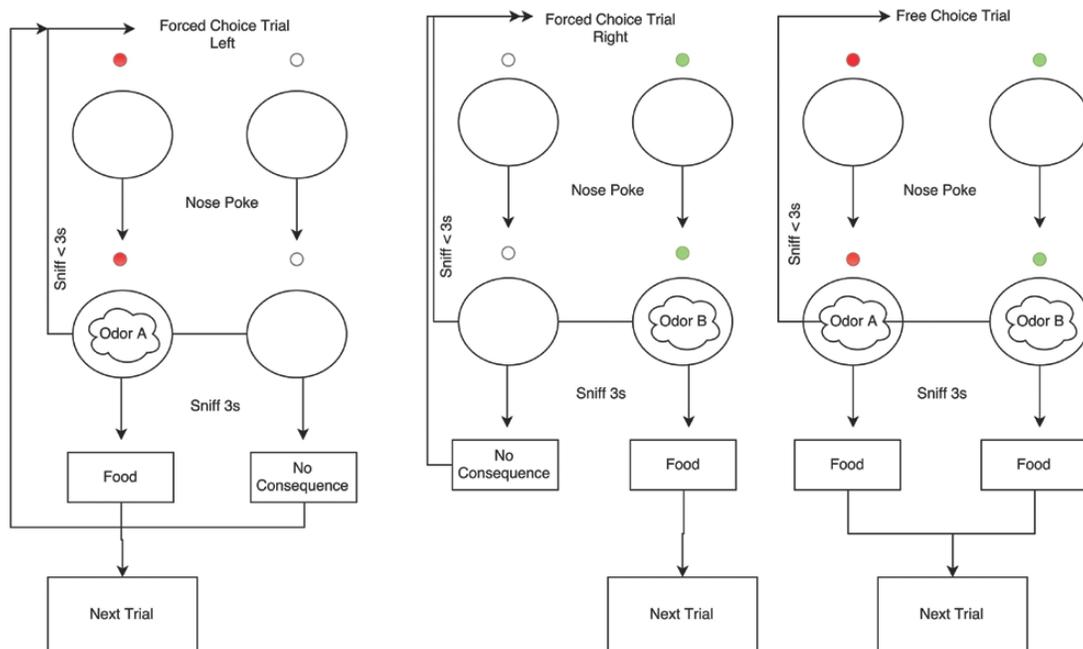


Figure 2. Diagram of the different trials for the odor preference assessment. Left shows a forced trial to the left, center a forced trial to the right, and right shows a free-choice trial. Circles represent the odor port. Small circles represent illuminated LEDs that were correlated with odor presence/absence.

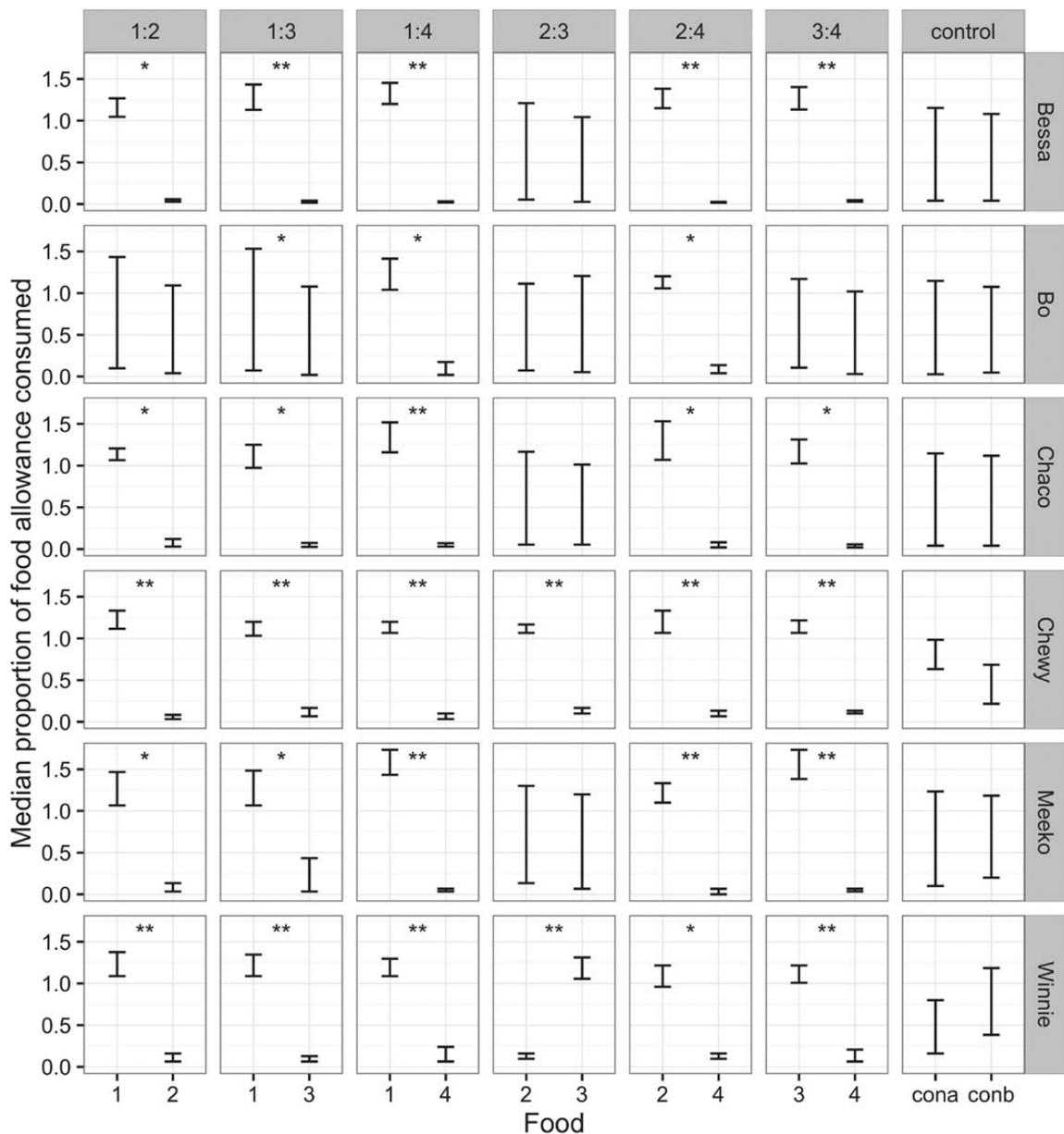


Figure 3. 95% Confidence intervals for the median proportion of the food allowance consumed across trials. Each dog is shown in a separate row, and each comparison in a separate column. * indicates $P < .05$ on a Wilcoxon signed rank test. ** indicates $P < .01$.

trial forced the dog to sample the odor in the left port. The order of presentation of the left and right forced trial was randomized. These trials were conducted to insure the dogs sampled both odors before engaging in free choice trials. During free choice trials, both ports were active, both LEDs were illuminated and the dog was free to choose either odor port. Both ports would provide the same food, which was a commercial dog treat that was distinct from the 4 tests foods. Choice during free trials provided a measure of preference between the odors.

Each session comprised a single comparison between the food on the left and the food on the right. There were a total of 8 comparisons. These included the 6 pairwise comparisons between the foods, a control comparison in which the same food was presented at both odor ports, and a second control comparison in which a food odor was presented to 1 port and no odor (clean air) was presented to the other port.

The order of presenting the comparisons was determined by a random selection procedure without replacement of the 8 possible comparisons (6 pairwise food comparisons and 2 controls). This procedure was repeated 3 times so that each comparison was presented for 3 sessions. Winnie, however, was an exception and due to scheduling was only able to complete 2 sessions of each comparison.

Ethical note

All procedures were approved by the Arizona State University Institutional Care and Use Committee. Both procedures were based on dogs' motivation to participate. Individuals were not food deprived or forced to carry out the test. The 2-bowl test and then the food odor preference test were presented at the time they normally would have received their meal. We did not observe any behavioral indicators of frustration during the first task, where the dogs were forced to stop eating after each of the 8 trials. When the dogs did

not complete all the sessions, their owners were informed so that they could provide a complement of food after testing. During the olfactometer assessment, dogs were given commercial dog treats and owners provided the dogs with normally scheduled meals.

Statistical analysis

Food preference

Food preference was investigated at the individual level for 2 dependent variables: first food chosen (defined as first food of which 1 g or more was consumed) and overall food consumed, defined as the total weight consumed of the food measured by the food scale. We first investigated the correspondence between these 2 measures using percent agreement and Cohen's Kappa to evaluate the rate at which the 2 measures agreed on the dog's preference. Due to the high agreement, we focused subsequent analyses on overall consumption. To identify a significant preference, at the individual and food comparison level, we conducted a Wilcoxon signed-rank test to compare the amount of 1 food consumed to the other for each comparison. At the group level, we used a Bradley–Terry Luce model (Bradley and Terry 1952; David 1963) from the *prefmod* package in R to transform pairwise comparisons to a linear ranking scale (Dittrich and Hatzinger 2009). A “win” was defined as the food that was consumed more during a trial, and the “losing” food was the comparison food.

Odor preference

Odor preference was evaluated at the individual and group levels for preference during free choice trials. To analyze preference at the individual level, a binomial test was used for each comparison. At the group level, we fit a mixed-effect logistic regression for each comparison that controlled for the side the foods appeared on to evaluate whether dogs responded to 1 odor at a greater rate than the comparison.

R scripts and accompanying data for all analysis are available in the supplementary materials.

Results

Food preference

Dogs typically made their food selection during the odor sampling period before the screen was removed. Overall, dogs only ate from both bowls (defined as a food weight loss of 1 g or more) on 13% of the trials and only ate 1.5 g or more from both bowls on fewer than 7% of the trials. Therefore, there was high concordance between preference measured as the first food selected and preference as measured by which food was consumed more. These 2 measures agreed on 89% of the trials (Cohen's Kappa: 0.86, 95% CI: 0.83–0.88). To explore whether there were predictors of whether the dog's first choice was also the food most consumed, we computed a logistic regression model in which agreement between the 2 measures (agree/disagree) was predicted by the overall intake ratio (weight of food A consumed/ weight of food A + food B consumed), the food allowance (the amount of food the dog could consume before the trial terminated), the identity of the dog, and the food comparison being made. The model was then subjected to backwards elimination using the step function. The final model indicated that the intake ratio ($\chi^2 = 5.4$, $df = 1$, $P = 0.02$) and dog identity ($\chi^2 = 27.9$, $df = 5$, $P < 0.001$) were significant predictors of the odds of an agreement. The greater the intake ratio, the greater the odds of an agreement (95% CI: 1.08–2.60), indicating the stronger the

preference, the more likely the first choice correctly predicted consumption. For dog identity, the dogs Bo and Chaco showed lower odds of agreement between the 2 measures than the other dogs (Bo 95% CI: 0.18–0.63, Chaco 95% CI: 0.19–0.69) indicating that their first choice was not as predictive of which food they would eat more of.

Overall, due to the high concordance between first choice and total food consumed, we will focus analyses on just the amount consumed of each food hereafter. Figure 3 shows the 95% non-parametric boot strapped confidence intervals for the median intake (as a proportion of the food allowance) across all comparisons for all dogs. Proportions of the food limit higher than 1 were obtained because the computer triggered an alert to the experimenter after the food limit had been reached, and there was a small delay before the experimenter could replace the screen preventing further food access. Figure 3 also indicates the significance of each comparison on a paired Wilcoxon signed rank test. Non-parametric analyses were conducted because data tended to show a bimodal distribution. Dogs typically either ate large quantities or near zero amounts of a food, rarely in-between. Figure 3 shows very clear preferences for Food 1 over Foods 2, 3, and 4. Food 4 is also clearly non-preferred to Foods 1, 2, and 3. In contrast, Foods 2 and 3 are either equally preferred or 1 dog may prefer Food 2 (Chewy) and another prefer Food 3 (Winnie). Looking at preference across dogs, Bo did not show such strong preferences as the other dogs, which might in part explain why his first choice was not as predictive of overall food consumption as it was for the other dogs. In addition, there were no significant preferences detected during the control sessions indicating that it was unlikely that unintentional stimuli were controlling the dogs' preferences.

Next, we fitted a Bradley Terry Model to yield a preference ranking of the 4 foods on one common scale. A model was fit that included the subject name, the replication number (1–4), and the trial number of the session (1–8) as subject specific covariates. The within-session trial number had no main effect on the preference rankings (Deviance = -6.51 , $df = 4$, $P = 0.16$). There was, however, a significant effect of the subject (Deviance = -99.10 , $df = 20$, $P < 0.01$) and replication (Deviance = -15.04 , $df = 4$, $P < 0.01$) indicating that the food rankings varied by subjects and across testing replications. The parameter estimates from the model including subject and replication effects is shown in Figure 4. Parameter estimates increased for Food 1 and preference for the less-preferred foods decreased across replications, leading to more extreme preference rankings across replications. For dogs Bo and Chaco, they initially showed little differentiation between the foods, but as testing continued across replications, they developed preferences.

When considering the efficiency of conducting 4 rounds of testing, Bessa, Chaco, Chewy, Meeko, and Winnie showed differentiation between products within the first round of testing, indicating that only 1 or perhaps 2 rounds are necessary to obtain clear preferences with pet dogs (see Figure 4). Next, we investigated the median intake ratios for each comparison across all dogs for each replication (See Supplementary Figure 1). The intake ratio is defined as the quantity of food A consumed divided by the quantity of food A plus food B on a given trial. A value of 0.5 indicates no preference, a value greater than 0.5 indicates preference for food A and less than 0.5 indicates preference for food B. The median intake ratio from the first replication correctly indicated the direction and significance of preference for all comparisons (See Supplementary Figure 1). Therefore, the same qualitative conclusions would be obtained by the first round of testing.

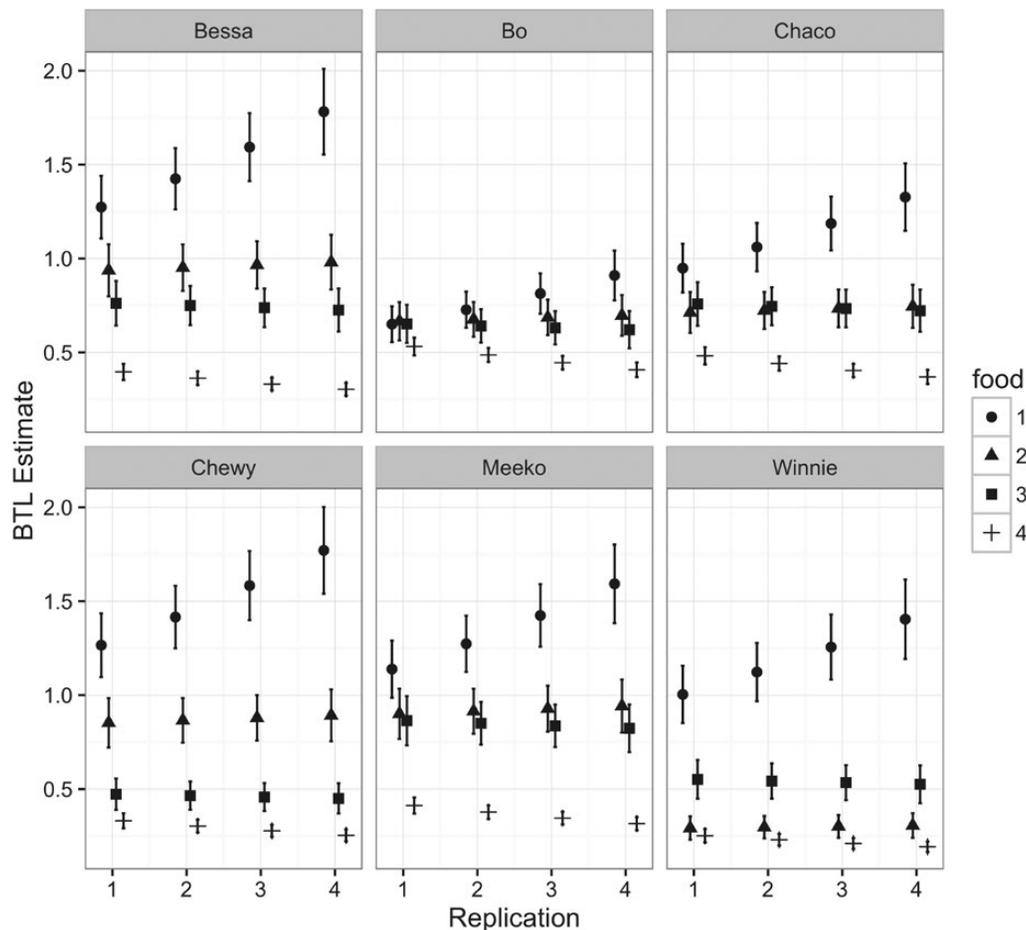


Figure 4. Parameter estimates from Bradley-Terry-Luce model. Panels show the estimates for each dog and replication and the standard errors.

To verify that the preferences obtained from our small number of subjects was not atypical and non-representative of dogs, we analyzed the preference data from a specialized external panel of 42 dogs on the same food products (same batches). The median intake ratio from the external panel for each food comparison was similar to our intake ratio (see Supplementary Figures 1 and 2). The qualitative conclusions for the median intake ratio for each food comparison were identical between our results and that of the specialized external panel (see Supplementary Figures 1 and 2).

Odor preference

To calculate odor preference, we calculated the proportion of *free choice* trials on which each odor was selected for each comparison. Because odors were only presented to one side only per session, we did not evaluate preference changes across replications as preference in a single session could be confounded with a side bias. This was not an issue for the food preference test, because food position was alternated *within* sessions counterbalancing food position each session. Figure 5 present the average results across dogs for each comparison (Supplementary Figure 3 shows the data for each dog). A mixed-effect logistic regression model was fit for each comparison in which the proportion of trials an odor was selected was predicted by the identity of the odor presented and controlled for the side the odor was presented on (left or right). Once side preferences were controlled for, the only odor comparison that remained significant was food odor vs. no food odor ($z = 5.80, P < 0.001$). No other odor

comparisons were significant at the group level. Bradley-Terry Luce modeling was not conducted because dogs did not show any significant preferences on the relevant comparisons.

Discussion

These results demonstrate the viability of testing food and odor preferences in pet dogs with minimal training. The modified 2-bowl test successfully discerned preferences between selected pet food products, and the odor preference assessment showed an absence of preferences for the odors of the same pet foods. The semi-automated 2-bowl procedure offers promise for in-home taste test panels.

We hypothesized that there would be an association between odor preference and consumption preference, however, in the absence of any odor preferences, it is not possible to correlate food and odor preferences. Prior research suggests that food odors are critical in dogs' ability to discriminate between preferred foods (Houpt et al. 1978, 1982); however, it remains unclear whether the odors from preferred foods are themselves more hedonically pleasurable, or whether the odors just allow dogs to discriminate among preferred foods.

Interestingly, dogs nearly always (89% of the time) consumed more of the food that was chosen first. This suggests that dogs by-and-large selected their food during a sampling phase and that product selection was likely based on odor or potentially visual information. In addition, the dogs that showed the lowest correspondence

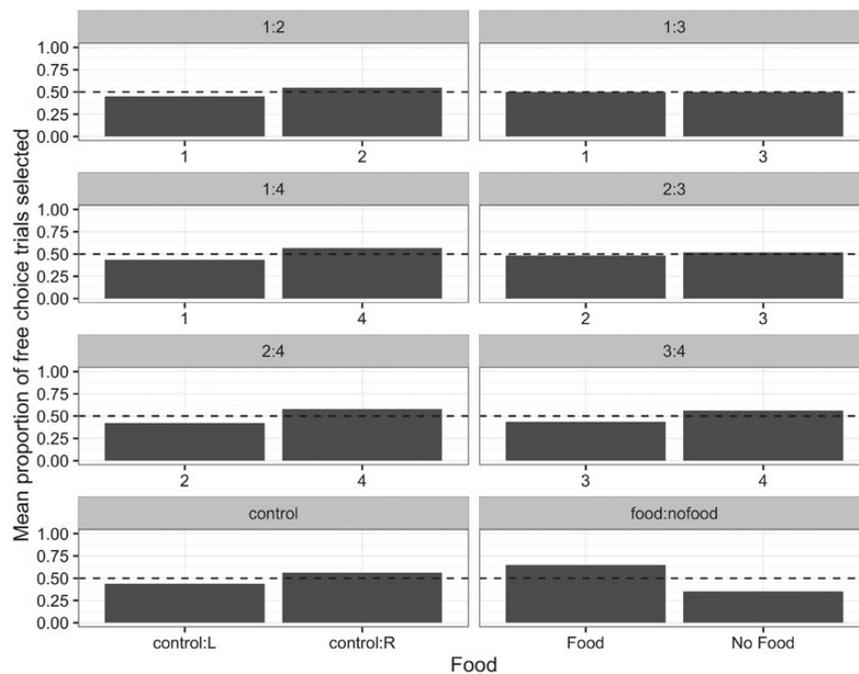


Figure 5. Mean across all subjects of the proportion of free-choice trials selected. A value 0.5 indicates no preference.

between first choice and food consumption (Bo and Chaco) were also the dogs that showed the least preference between products in the first session.

The pattern of consumption observed here, that when dogs have a preference, they tend to largely consume the preferred food only, rather than consume a diverse mixture, seems to be consistent with what is usually observed in dog panel evaluation tests. We analyzed the results of a standard 2-bowl test with 42 dogs comparing the same products as in this study. The distribution of the intake ratio showed that even in this case, dogs tended to show exclusive or near exclusive preference for 1 food over the other (see Supplementary Figure 4). The data from [Smith et al. \(1984\)](#) also showed that several dogs would exclusively eat one food. Some dogs would only switch the food consumed after exhausting all the food in the other bowl; however, there were a few dogs that tended to switch more often ([Smith et al. 1984](#)). These feeding patterns may reflect the opportunistic feeding strategies of feral dogs in which resources such as garbage or animal carcasses are monopolized ([Scott and Causey 1973](#); [Butler and Toit 2002](#)), however, further study is needed with longer term observations of canine feeding behavior.

One concern with using in-home taste panels, is that the dogs are not trained panelists which have learned to be discriminating in their food choices. Our testing procedure was designed to limit this issue by giving dogs multiple trials per session and implementing an odor sampling period. During this period, dogs had olfactory and visual access to the 2 foods for 15 s, but a small screen prevented them from accessing the food. This sampling period was designed to reduce impulsive choices such as picking the first bowl approached, and give the dog a period to decide between the bowls. This forced sampling period is similar to a recent report which found that measures of investigation and sniffing an inaccessible food predicted consummatory preference for that food in a puzzle device ([Thompson et al. 2016](#)).

An additional concern with home panels is that they may be biased against foods they are typically fed ([Griffin et al. 1984](#)). This

is unlikely to be the case with our results, because [Griffin et al.](#) noted that pre-feeding effects largely disappeared within the first couple of days. Given that our study was conducted over more than a month of testing and we saw no preference reversals within that time period, it is unlikely prior feeding had a significant impact.

With our procedure, the qualitative individual preference rankings were obtained by the first replication for 5 of the 6 dogs (Bo being the exception). However, these dogs also showed signs of learning, in which preferences became more extreme across replications, and Bo began to show preferences in concordance with the other dogs. Interestingly, across the 6 weeks of testing, dogs that showed an initial preference showed no apparent change for the preferred food, except for increases in the strength of the initial preferences. The present results indicate that, not surprisingly, our dogs tend to show similar preferences (for the food products selected) and that very little information was gained beyond the first and especially the second replication of the comparisons.

Questions remain, however, as to the extent to which these results will generalize to other foods that may have greater overlap in preference. Therefore, additional research would need to be conducted to extend the results to a greater variety of products and with more dogs. Our aim here was to study the possible correlation between *individual* food and odor preferences for specific pet-food products and we therefore opted for more in depth study of a small sample.

The present 2 bowl procedure had several convenient features in addition to its forced sampling period. Each testing session contained 8 trials which allows for the counter balancing of food placement, and is a sufficient number of trials to identify a statistically significant preference in a few dogs. Also, the automated data collection served several other functions. It reduced the possibility of observer mistakes and allowed for a program to control the determination of which side a food was to appear on, which foods were to be compared in a session, and when a dog had consumed an appropriate ration. This allowed us to circumvent issues regarding overconsumption, weight gain, and satiation in 2-bowl tests because we were able

to stop testing once the computer registered adequate consumption. Last, our use of a control condition and blinded coding of the foods helps confirm that results were due to preferences of the dogs and not experimenter bias.

One limitation to these results, however, is that due to the use of foods that vary in nutritional content, dogs' intake might have been influenced by differential nutritional feedback such as overall protein content. Dogs tend to eat around 27–30% of metabolizable energy from protein and choose a larger fat to carbohydrate ratio (Tórres et al. 2003; Hewson-Hughes et al. 2013). However, this result is obtained when dogs are given bland food or foods with similar flavors (Tórres et al. 2003). When one food is sweetened, dogs' selection can be biased towards a higher sucrose, lower protein diet (Tórres et al. 2003). The present results, however, only show preference differences between food products, and does not disentangle whether the differences are driven by nutritional content or the flavor additives of the foods. Given that dogs showed similar preferences in their first round of assessment as their last round, this suggests the results we observed are due to palatability; however, additional study is necessary to confirm.

Our odor preference assessment results are more nuanced. The only overall preference observed was between the smell of a food odor versus no food odor at all. We expected dogs would prefer to sniff the odors of preferred foods over non-preferred foods. There are several potential explanations for why we did not observe this. The first is that the reinforcing properties of the 2-food odors were not sufficiently strong to maintain differential responding. Both choices led to food, so they perhaps made the simplest response to obtain it, without being motivated sufficiently to select the preferred odor. This explanation falls in line with the findings of Houpt et al. (1978). They found that although dogs showed an initial preference for a bland food with meat odor blown across it, but within several testing sessions, the odor alone was insufficient to maintain differential responding. In addition, the results from Thompson et al. (2016) indicated that dogs' investigation of an inaccessible treat drops around 32% within just 2 trials. In our case, the odor alone may not have been a sufficient motivator to maintain differential responding between the 2 odor ports across multiple trials and sessions. It should be noted, however, that it is possible that by conducting the feeding trial first for each dog, the experiences during the feeding trial may have influenced olfactory preferences. However, given that we did not observe clear olfactory preferences but saw strong feeding preferences, it is unlikely that experience during the feeding trials was a significant factor in the olfactory testing.

There are also alternative explanations for the olfactory results. One is that dogs failed to "recognize" that they had a choice at all. Although this is possible, the difference observed on the food versus no food trials suggests that they were able to choose odor over no odor. Another alternative is that dogs failed to recognize the food odors, however, this is also unlikely given dogs could discriminate food odor from no odor. In addition, during pilot testing with the olfactometer, the experimenters noted very similar perceptual experiences between the odor produced at the odor port compared to sniffing directly at the food products.

In conclusion, the results demonstrate that our 2-bowl test, which utilizes a forced sampling period and automated data collection identifies individual preferences between the tested food products in pet dogs. Our odor preference test, however, did not show any clear preferences except for food odor over no food odor. This suggests additional manipulation is needed to identify a method to evaluate odor preferences between different food products to further research

in understanding how the hedonic value of food odors influences feeding behavior in dogs.

Supplementary material

Supplementary material is available at *Chemical Senses* online.

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