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Taste threshold determination and side-preference in captive cockatiels (*Nymphicus hollandicus*)

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Abstract

The taste thresholds of caged cockatiels (*Nymphicus hollandicus*) for aqueous solutions of sodium chloride, citric acid, and sucrose were studied using two-choice taste-preference tests. The effects of location on the threshold were tested by putting the flavored solution in either the preferred or non-preferred locations (i.e. sides of cages) and offering water in the opposite location. Four parameters (total consumption, consumption from preferred side, consumption from non-preferred side, and proportion of test solution consumed) were measured at the end of 3-day test periods. Experiments were repeated with increasing concentrations of test flavors until intake variables were significantly ($p < 0.05$) affected. The results showed that birds distinguished ($p < 0.05$) between purified water and 0.16 mol l^{-1} sodium chloride, 0.36 mol l^{-1} sucrose, or pH 5.5 citric acid. The likelihood of detecting a taste threshold was greater for sodium chloride and citric acid when these solutions were placed on the preferred side. In contrast, sucrose sensitivity was greater when this solution was offered on the non-preferred side. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Cockatiel; Psittacine; Taste; Preference test; Side-preference

1. Introduction

In contrast to mammals, many birds have a poor sense of taste. When the number of taste buds is counted, birds have relatively few as compared to humans or other mammals. For example, while humans have approximately 9000 taste buds, chickens have 250–350 taste buds and pigeons, only 37–75 (Kare and Mason, 1986; El Boushy et al., 1989). Parrots have between 300 and 400 taste buds; the highest number among the

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birds studied (Kare and Mason, 1986). Avian taste buds are found in the oral cavity on the floor of the pharynx and at the base of the tongue (El Boushy et al., 1989).

Despite their paucity of taste buds, taste has been demonstrated to be an important factor in determining food acceptance and avoidance for birds. For example, nectarivorous birds, such as hummingbirds and sunbirds, can distinguish between different nectars based on sugar composition (Lloyd, 1989; Jackson et al., 1998) and concentration (Hainsworth and Wolf, 1976). Additionally, compounds with an offensive taste can be used to repel birds. Application of methyl anthranilate has been used to reduce crop damage caused by birds (Cummings et al., 1994). Also, it has been demonstrated that high levels of secondary plant compounds, which often produce an astringent feeling in the oral cavity, prevent Canada geese (*Branta canadensis*) from eating certain plant foodstuffs (Buchsbaum et al., 1984). These same secondary compounds have been proposed to be used as natural chemical repellents to protect crops from damage and loss to herbivorous birds (Crocker et al., 1993).

Kare and Mason (1986) state that ''research on taste in birds has been handicapped by the general assumption that they live in the human sensory world.'' Indeed, it is clear that in the case of some chemical compounds (such as methyl anthranilate), humans and birds have very different taste responses to the same compounds (Kare and Beauchamp, 1984; Kare et al., 1957; Cummings et al., 1994). Despite this, researchers often divide the avian sense of taste into the four classical categories of sweet, salt, sour, and bitter (Duncan, 1960; Brindley, 1965; Brindley and Prior, 1968; Gentle, 1972).

Apart from the specific appetites for salts or minerals, all taste stimuli are important to our understanding of food choice. El Boushy et al. (1989) state that ''the function of taste is to encourage the ingestion of nutrients, to select among feed which is palatable and to avoid those that are toxic.'' Because many psittacine species are endangered due to poaching and habitat loss, aviculturalists have worked to develop a set of husbandry conditions for captive propagation of psittacines (Millam, 1999). However, little is known about dietary needs of parrots and the role that taste plays in the birds' food choices. The role of taste as a food choice factor is an important consideration for diet development. The understanding of food choice based on taste is especially crucial to understand when raising birds in captivity that will later be released into the wild. In addition to food choice, the sense of taste is important in determining the role of geophagy in parrots (Gilardi et al., 1999).

Cockatiels (*Nymphicus hollandicus*) were used as our study organism. These birds are small granivorous psittacines native to Australia and are found throughout most of the country including the hot, arid central region (Jones, 1987). Many vertebrates living in arid regions similar to the habitat of the cockatiel are salt-deficient (Blair-West et al., 1968). Additionally, specific appetites for salt are common among these animals (Blair-West et al., 1968). The response of captive cockatiels to a sodium chloride solution gives some insight on the taste threshold of these desert birds in salt-sufficient situations.

The most common method of testing taste-preferences is a two-bottle test. This test involves dissolving the material in water and presenting each bird with a choice of the test solution or purified water (Kare and Mason, 1986). With one-bottle tests, the consumption by one group of birds offered only the test solution is compared to the consumption of another group of birds offered only water. Because factors such as thirst or dehydration may mask the effects of taste on consumption in one-bottle tests, tests utilizing two bottles better measure taste perception (Pfaffmann, 1956). However, when presenting side-by-side choices the side-preference must be addressed. The issue of side-preference has been dealt with in different ways when designing taste-preference experiments for birds (Bartholomew and Cade, 1958; Harriman and Fry, 1990; Jackson et al., 1998).

The purpose of these experiments was to determine the most appropriate and statistically powerful method of measuring the taste threshold for sodium chloride, sucrose, and pH (citric acid buffer) of captive cockatiels. Specifically, attempts to minimize the effects of pre-existing side-preferences were made, and the effects of placing the taste stimulus in either the preferred or non-preferred locations were examined.

2. Materials and methods

Cockatiels used in these experiments were part of the Department of Animal Science's research and breeding flock at the University of California, Davis. The cockatiels ranged in age from 1- to 18-years-old. Both male and females birds were included in the test group. Cockatiels were individually housed in indoor cages ($30 \times 30 \times 60$ cm). Room temperature was maintained at 23°C. Light/dark cycles were kept constant during each experimental series and were either 9L:15D or 15L:9D, depending on the season. The birds were provided with food and water for ad libitum consumption. The diet fed was a pelleted formulation for small psittacines (Maintenance Crumbles, Roudybush, Cameron Park, CA). During the taste-preference trials, each cage was fitted with two 100-ml capacity water bottles with volume graduations in 1-ml increments (Bio-Serve, Frenchtown, NJ). The bottles were installed in the lower, rear corners of the cages on the wall opposite of the food dispenser. Each bottle had a small drinking surface (1.5 cm in diameter). In each cage, the drinking surfaces were 25 cm apart. The water used throughout all experiments was distilled water, which had been purified through a Milli-Q Water System (a carbon filter, two ion-exchange columns, an endotoxin filter, and a 0.20-μm ultra-filter) (Millipore, Boston, MA).

In the present experiments, sucrose ($C_{12}H_{22}O_{11}$, Sigma, St. Louis, MO, catalog #S-8501), sodium chloride (NaCl, Sigma, #S-3014), quinine hydrochloride and a buffer made of sodium citrate ($C_6H_5Na_3O_7 \cdot 2H_2O$, Sigma, #S-4641) and citric acid ($C_6H_8O_7$, Sigma, #C-0759) were used to represent sweet, salt, bitter, and sour categories, respectively. Sourness was defined as pH and was achieved by varying the pH of a 0.05-mol l^{-1} citrate buffer system. Because of the extreme sensitivity to quinine hydrochloride, the threshold was overshot at the first level tested (0.0001 mol l^{-1}). For this reason, it was excluded from this study, but will be the subject of a future study. All research was approved by the Animal Care and Use Committee at UC Davis.

The birds were provided with water on both sides for a period of 3 days (70–74 h). This period, called the equilibrium period, was used to determine the total amount and preferred side of water consumption. The amount of water consumed during the 3 days was determined from the difference in the initial and final amounts of water in the bottles. These data indicated that there was considerable variation among individual birds in the total amount and side-preference of water consumption. Therefore, birds were ranked according to the strength of their preference, as determined by the proportion of consumption from each side. The birds were then assigned to one of three experimental groups in a manner that equally distributed the side-preferences among the groups. The three treatments were: control group that continued to receive water on both sides; lower level taste group that received the taste compound on one side and water on the other; and the higher level taste group that received an incrementally higher level of the taste compound on one side and water on the other. Treatment groups were composed of six to eight birds depending on the period. Excessive consumption during the equilibrium period (> 80 ml from one side and/or > 100 ml from both sides) was grounds for removing a bird from the experiment.

Consumption from each of the sides during the 3-day experimental period was determined and the results were expressed as: consumption from the preferred side, consumption from the non-preferred side, total consumption and the proportion of consumption on the non-preferred side to total consumption (Proportion). A significant shift in one or more of the consumption measures of the test group compared to the same measure of the control (water-only) group indicated that the birds perceived the taste of the test solution and altered their drinking behavior. An experimental series with progressively increasing concentration of the test compound was conducted for each taste stimulus.

The taste threshold was defined as the minimum concentration of a test compound that resulted in a significant change in the consumption pattern of one or more of the parameters measured. In the first experimental period, the birds were given two concentrations of the test compound thought to be well below their threshold. If these levels did not alter their consumption pattern, the concentrations of the two test treatments were increased. An equilibrium period of 3 days where purified water was on both sides separated each experimental period. These equilibrium periods were used to measure side-preference and reassign the birds to treatment groups as previously described.

Test compounds were first tested on the non-preferred side. The highest concentration that did not significantly impact consumption as well as the threshold concentration (as determined with the test compound on the non-preferred side) were used as the starting concentrations for an experimental series with the same test compound placed on the preferred side.

The same flock of birds was used for each experimental series. Over the 10-month test period, individuals were exposed to all solutions in the following order: sodium chloride on non-preferred side, sucrose on non-preferred side, sodium chloride on preferred side, sucrose on preferred side, citric acid buffer on non-preferred side, and citric acid buffer on preferred side. The effects of prior exposure of the birds to unrelated chemicals are unknown.

2.1. Data analysis

Data for consumption from the preferred side, consumption from the non-preferred side, total consumption, and the Proportion of the test solution consumed from each experimental period were analyzed by One-way ANOVA. Experiments were repeated with increasingly higher concentration (or lower pH) of the test compound until a treatment was found that was significantly different ($p < 0.05$) from the control (water-only) group for one or more of the recorded parameters. When a $p < 0.05$ was obtained, differences between individual treatment means were determined by least significant difference (LSD). If a treatment mean was significantly different from the control mean by LSD, the experimental series was stopped. In the case that there was a significant ANOVA ($p < 0.05$), but the LSD did not indicate that a treatment mean was significantly different from the control mean, the trial was repeated with the same test solution concentrations or pH. Repeated data sets included sodium chloride on the non-preferred side at concentrations of 0.12, 0.16, 0.18 mol l^{-1}; citric acid buffer on the non-preferred side at pH 5.0; sucrose on the non-preferred side at concentrations of 0.45 and 0.56 mol l^{-1}; and sucrose on the preferred side at 0.36 and 0.45 mol l^{-1}. Data from these replicate experiments were analyzed using a general linear model (GLM) with treatment, repetition, and the treatment–repetition interaction as main effects. In most cases, the effects of both the repetition and the interaction were not significant ($p > 0.20$), and the data were pooled and analyzed by One-way ANOVA and LSD means comparisons. In some cases (sucrose on preferred side at concentrations of 0.36and 0.45 mol l^{-1} for non-preferred and Proportion parameters), repetition accounted for sufficient variation ($p < 0.20$) and was left in the model. In these cases, differences between control and test measures were determined by single degree of freedom contrasts. To compare the effects of different solution concentration within the experimental series, the treatment means were standardized by expressing the consumption parameter means of treatment birds as a percentage of the mean of the same parameter of the control birds.

Similar threshold levels were found when the test solutions were placed on the preferred and non-preferred sides so we desired to determine which of these two experimental approaches were most efficacious. Because of variation in the sample size of the treatment groups (n) and in the standard deviations, the data were analyzed by power statistics using JMP (SAS, Cary, NC) in order to compare the relative effectiveness of placing the flavor solution on the preferred vs. non-preferred sides. The power was calculated using all data from each side for the threshold concentration or pH. Power calculations resulted in a probability of achieving a $p = 0.05$ for a range of values for n. These calculations used Δ, the effect size or the separation of the means, and Σ, the standard deviation of the data set, to determine these probabilities. The more powerful experimental design (test compound in preferred or non-preferred side) was determined by which had the higher probability of being significant for n ranging from 12 to 52 in increments of 4.

3. Results

3.1. Equilibrium periods

During the equilibrium periods, initial side- preferences were monitored. Preference ratios ranged from < 0.1 (strong preference for side one) to > 0.9 (strong preference for side two). The preference ratios appeared to be equally distributed between birds both before and after exposure to chemical stimuli. The average preference ratio for the whole flock and within treatment groups was typically near 0.5. While it was not tested, it appeared as if side-preference ratio may relate to the location of the bird in the cage battery (i.e. birds on the left side of the battery appear to prefer the right water bottle and vice-versa)

3.2. Experiment 1: sodium chloride

The sensitivity of cockatiels to a salty substance was first tested by placing a sodium chloride solution on the non-preferred side and purified water on the preferred side. The eight test solutions of sodium chloride had concentrations ranging from 0.02 to 0.18 mol l^{-1} (Fig. 1a). At 0.12 mol l^{-1}, none of the consumption parameters differed significantly from the same parameters of the control group. At 0.16 and 0.18 mol l^{-1}, the consumption from the treatment non-preferred side (sodium chloride solution) was significantly less than the consumption from the control non-preferred side (water) ($p = 0.004$ and 0.016, respectively). Additionally, at both of these levels, the treatment Proportion was also significantly less than control Proportion ($p = 0.003$ and 0.021, respectively).

For all birds offered the 0.16-mol l^{-1} sodium chloride solution, the total fluid consumption was significantly less than that of the control ($p = 0.029$). The same trend of a decreasing total consumption occurred for the 0.18-mol l^{-1} sodium chloride group, but this result was not significant ($p = 0.085$).

Based on the results of Experiment 1a, sodium chloride was placed on the preferred side at 0.16 and 0.18 mol l^{-1} (Fig. 1b) and purified water was placed on the non-preferred side. At 0.18 mol l^{-1}, the consumption from the preferred side (sodium chloride solution) was significantly less than the consumption from the control preferred side (water) ($p = 0.011$). Additionally, the consumption from the non-preferred side (water) was significantly greater than the consumption from the control non-preferred side (water) at 0.18 mol l^{-1} ($p = 0.018$). Lastly, the Proportion was significantly greater than the Proportion of the control group at both 0.16 and 0.18 mol l^{-1} ($p < 0.001$).

Regardless of which side the flavor was placed, the presence of 0.16 mol l^{-1} sodium chloride significantly changed the drinking patterns when compared to the control patterns. Therefore, the taste threshold for cockatiels is between 0.12 and 0.16 mol l^{-1}. Because the number of birds used and the magnitude of the response varied for these two experiments, power statistics were applied to the threshold data (0.16 mol l^{-1}) to determine which experimental procedure had the highest probability of achieving significance. The three statistically significant parameters (consumption from preferred, consumption from non-preferred, and Proportion) tested indicated that the experimental design was more powerful (higher probability of significance) when sodium chloride was placed in the preferred bottles.

3.3. Experiment 2: citric acid

To determine the sensitivity of cockatiels to pH, a 0.05-mol l^{-1} buffer solution of citric acid and sodium citrate was prepared at pH 5.5 and 5.0 using the proportions

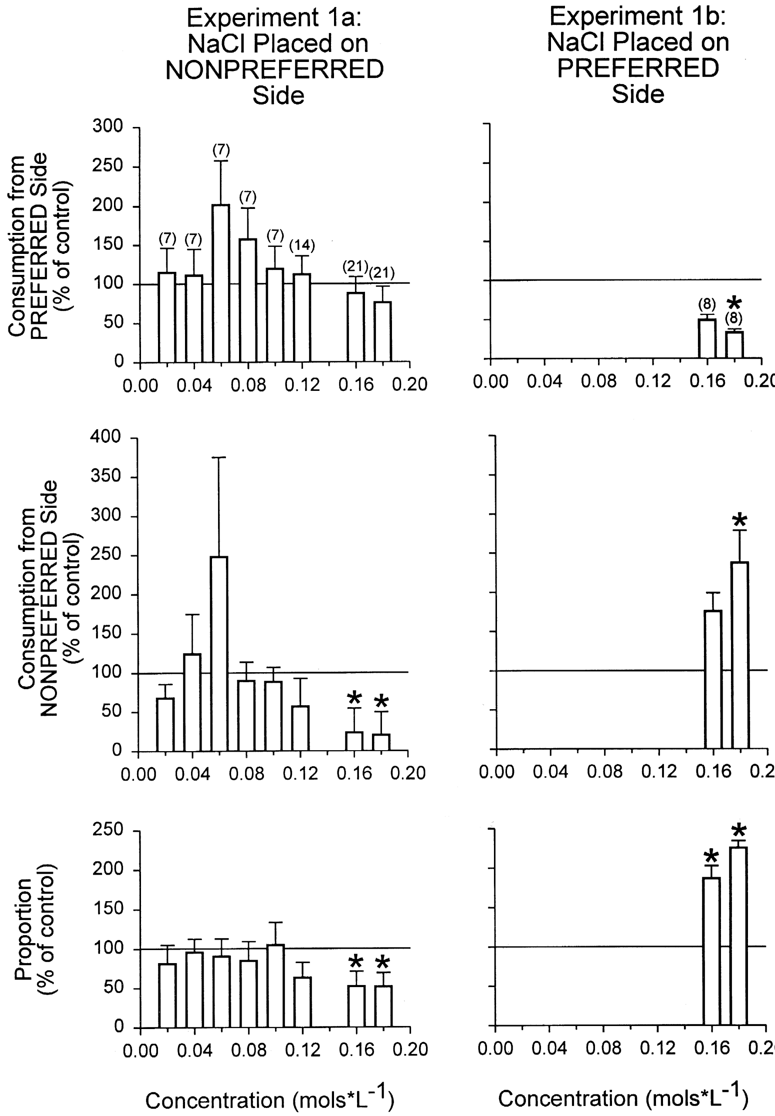

Fig. 1. Comparison of the effects of different concentrations of sodium chloride placed on previously established non-preferred (a) and preferred (b) sides. The consumption measures of control birds that were provided water on both sides were normalized to 100% and are indicated by the horizontal line at this value. Open bars indicate consumption by treatment groups ($\pm$SEM) expressed as a percentage of the control group. Stars represent significant changes from the control. The numbers in parentheses indicate the sample size.

indicated by Gomori (1955). The solutions were first offered to the birds on the non-preferred side. No significant differences were found between the control group and the pH 5.5 treatment group for any of the consumption measurements (Fig. 2a). At pH

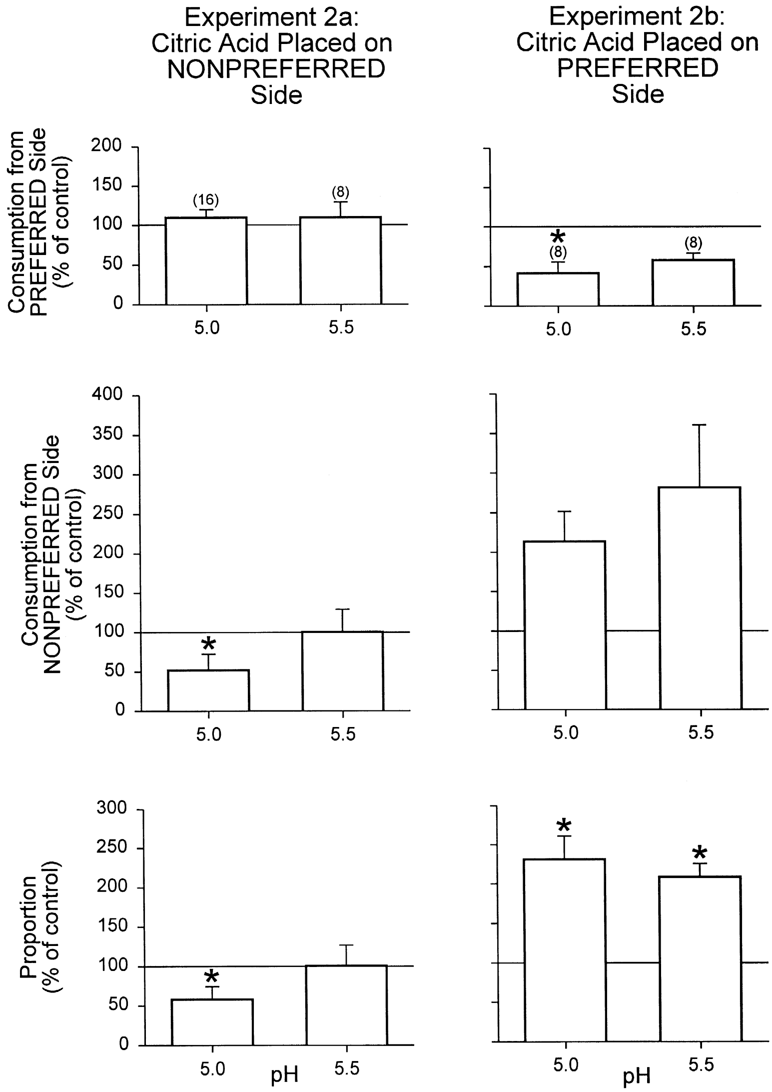

Fig. 2. Comparison of the effects of different pH values of a 0.05-mol l^{-1} citric acid buffer placed on previously established non-preferred (a) and preferred (b) sides. The consumption measures of control birds that were provided water on both sides were normalized to 100% and are indicated by the horizontal line at this value. Open bars indicate consumption by treatment groups ($\pm$SEM) expressed as a percentage of the control group. Stars represent significant changes from the control. The numbers in parentheses indicate the sample size.

5.0, consumption from the non-preferred side ($p = 0.025$) and the Proportion ($p = 0.014$) were significantly less than the same parameters of the control group.

Next, the buffered citric acid solutions at pH 5.5 and 5.0 were placed on the preferred side (Fig. 2b). The consumption from the preferred side of the pH 5.0 treatment group was significantly less than the consumption from the preferred side of the control group. Additionally, the Proportions for pH 5.5 and 5.0 treatment groups were significantly greater than the control group Proportion ($p = 0.001$). Therefore, the taste threshold for 0.05 mol l^{-1} citric acid buffer is likely to be around pH 5.5.

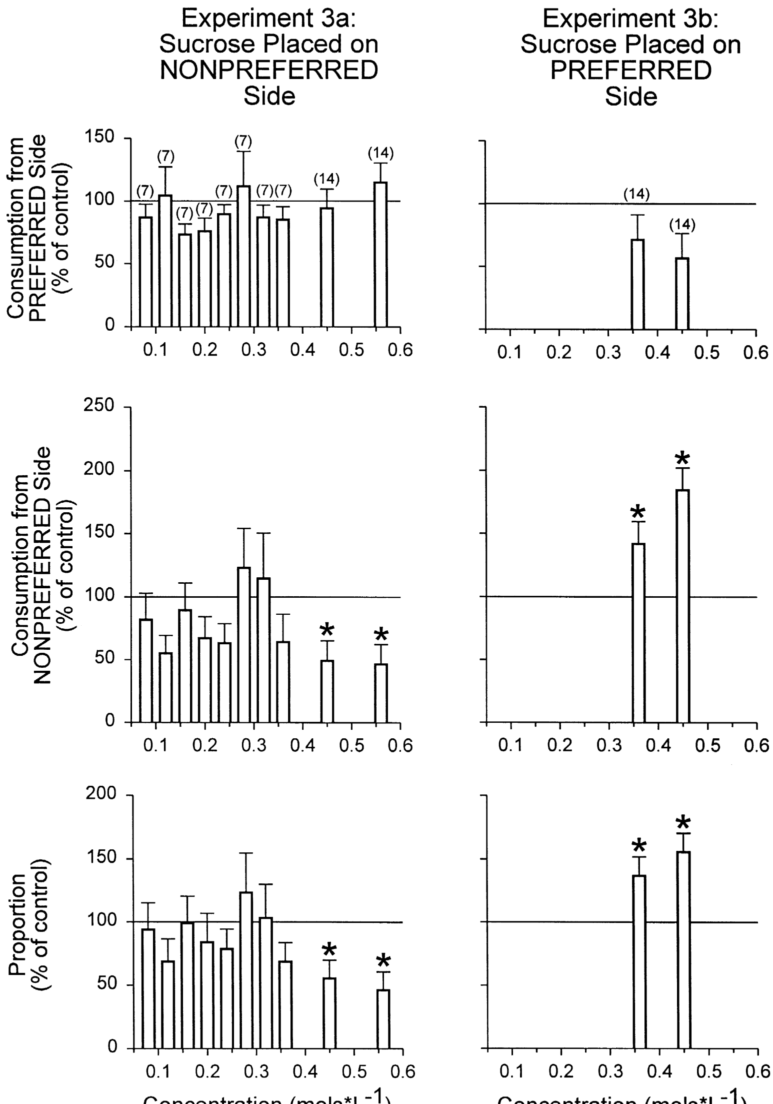

Fig. 3. Comparison of the effects of different concentrations of sucrose placed on previously established non-preferred (a) and preferred (b) sides. The consumption measures of control birds that were provided water on both sides were normalized to 100% and are indicated by the horizontal line at this value. Open bars indicate consumption by treatment groups ($\pm$SEM) expressed as a percentage of the control group. Stars represent significant changes from the control. The numbers in parentheses indicate the sample size.

Power statistics were also calculated for the citric acid buffer data. The probability of achieving significance for preferred consumption, non-preferred consumption, and Proportion was calculated and indicated that the experimental design was more powerful when the test solution was placed on the preferred side than on the non-preferred side.

3.4. Experiment 3: sucrose

Sucrose was used to determine the threshold level of sweetness. Sucrose was first tested on the non-preferred side. Ten concentrations ranging from 0.08 to 0.56 mol l^{-1} were tested (Fig. 3a). At 0.45 and 0.56 mol l^{-1}, the consumption from the non-preferred side was significantly less than that of the non-preferred side of the control group ($p = 0.003$). Additionally, at 0.45 and 0.56 mol l^{-1}, the Proportion was significantly less than the control Proportion ($p = 0.001$).

When sucrose was placed on the preferred side, only 0.36 and 0.45 mol l^{-1} were tested (Fig. 3b). The non-preferred consumption from the 0.36- and 0.45-mol l^{-1} groups were significantly greater than the non-preferred consumption of the control group ($p = 0.0217$ and $p < 0.0001$, respectively). Also, the non-preferred consumption from 0.36 mol l^{-1} was significantly less than the non-preferred consumption from 0.45 mol l^{-1} ($p = 0.0190$). Additionally, the Proportion for the 0.36- and 0.45-mol l^{-1} groups were significantly less than the control Proportion ($p = 0.0168$ and 0.0005, respectively).

The sucrose on the preferred side series was the only experimental series in which a main effect of repetition was significant. For the two consumption parameters (non-preferred consumption and Proportion) for which repetition was significant, the first repetition was significantly less than the second ($p = 0.0018$ and 0.0047, respectively).

Again, power statistics were used to determine whether the placement of the sucrose taste stimulus on the preferred or non-preferred sides was more powerful. For the 0.36-mol l^{-1} treatment data, the three tested consumption parameters were all more readily detected when the solution was placed on the non-preferred side.

Additionally, because of the large number of repetitions using the same birds, the data for sucrose on the non-preferred side was subjected to a test to determine if the birds were habituating to the increasing sucrose concentrations. A GLM was run testing the data for effects from the repetition or from the treatment by repetition interaction. No significant effects were found for any of the consumption measures, indicating that the birds were not habituating to the sucrose solution over time.

4. Discussion

In these experiments, taste thresholds were determined by measuring a behavioral response. The thresholds, therefore, were not acuity thresholds per se. Instead, the thresholds are more appropriately viewed as preference thresholds. That is to say that the consumption parameters changed when the birds significantly preferred or rejected the various solutions, which might not always be the same concentration that they first tasted the solutions. Thus, it is possible that the preference thresholds are overestimating the acuity thresholds.

In general, the placement of the solution on preferred or non-preferred sides did not have profound effects on the threshold determination. In the cases of sodium chloride, the same threshold was found regardless of placement. However, small differences were found in the thresholds for the citric acid buffer and the sucrose solution. In the case of the citric acid buffer, a threshold 0.5 pH units higher was determined when the solution was placed on the preferred side. The sucrose threshold was determined to be 0.09 mol l^{-1} lower when the test solution was offered on the preferred side. Because the sample sizes varied, the effects of test solution placement on threshold were often obscured. To elucidate the effects of side placement, the power statistics were considered. The sodium chloride and citric acid thresholds were more powerfully detected when the test solutions were placed on the preferred side. However, the sucrose threshold was more powerfully detected when the solutions were placed on non-preferred side.

When thinking about the placement of the taste stimuli, it is easy to imagine that one side or the other may provide greater sensitivity. One could hypothesize that attractive flavors would be determined with greater sensitivity on one side (the non-preferred, for example, because an increase in consumption would be easier to demonstrate) and that repulsive flavors would be determined with greater sensitivity on the other side. This lack of a clear rationale for placing the test solutions on one specific side led us to test both sides. However, our findings shed little light on where to place the test solutions. Given that direction of change of consumption was similar across taste stimuli, it is somewhat surprising that for one stimulus the non-preferred side is more sensitive, and for the others the preferred side is more sensitive. It is unclear why this pattern emerged.

At a concentration of 0.16 mol l^{-1} sodium chloride, consumption of the test solution was significantly less than the consumption of purified water. Bartholomew and Cade (1958) report that house finches (*Carpodacus mexicanus*) significantly reduce their consumption of a sodium chloride solution of 0.20 mol l^{-1}. The sodium concentration in blood ranges from 0.132 to 0.150 mol l^{-1} in captive cockatiels and 0.130 to 0.157 mol l^{-1} in other captive psittacines (Lane, 1996; Polo et al., 1998). The change in the consumption patterns at 0.16 mol l^{-1} sodium chloride could be linked to plasma chemistry of cockatiels. The best understood gustatory transduction mechanism of sodium chloride is the amiloride-sensitive sodium channel. These channels are, in fact, regulated by the same hormones that are involved with water and salt homeostasis (Herness and Gilbertson, 1999). Thus, these channels offer a possible explanation for the rejection of hypertonic sodium chloride solutions.

Other birds also alter consumption patterns when offered hypertonic salt solutions. Harriman (1967) notes a strong aversion (defined as ‘‘consumption of a test solution at half the rate of water’’) to hypertonic sodium chloride solutions starting at 0.20 mol l^{-1} for laughing gulls (*Larus atricilla*) and herring gulls (*L. argentatus smithsonianus*). Based on the same definition of strong aversion, Harriman and Kare (1966) find that starlings (*Sturnus v. vulgaris*) taste 0.15 mol l^{-1} sodium chloride; herring gulls, 0.20 mol l^{-1}; and purple grackles (*Quiscalus q. quiscula*), 0.50 mol l^{-1} (the next higher level tested after 0.20 mol l^{-1}). With common ravens (*Corvus corax*), a significant inverse relationship between sodium chloride solution concentration (0.05, 0.10, 0.50, and 1.00 mol l^{-1}) and consumption levels results (Harriman and Fry, 1990). However, because the authors do not report mean comparisons, the specific threshold between 0.05 and

1.00 mol l^{-1} cannot be determined (Harriman and Fry, 1990). Kare et al. (1957) report that Rhode Island Red-Barred Plymouth Rock crossbreds reject a 2.0% (0.34 mol l^{-1}) solution. However, Gentle (1972) reports a significant rejection of only 0.05 mol l^{-1} sodium chloride vs. distilled water in Brown Leghorns.

Cade (1964) reports that black-rumped waxbills (*Estrilda troglodytes*), zebra finches (*Taeniopygia guttata castanotis*), and budgerigars (*Melopsittacus undulatus*) all significantly increase their consumption of a sodium chloride solution at 0.05 mol $l^{-1.}$ While not found to be significant, a trend of increasing consumption was observed in our study for 0.04 and 0.06 mol l^{-1} sodium chloride. Throughout our study, the cockatiels were maintained on a salt-sufficient diet with 0.18% Na and 0.27% Cl. The lack of a deficiency of or a specific appetite for sodium or chloride could be reasons we did not observe significant increases in the consumption of sodium chloride.

With the exception of 0.16 mol l^{-1} sodium chloride on the non-preferred side, placing a novel taste on either the preferred or non-preferred water side did not impact the total fluid consumption. In the case of the one exception, total fluid consumption was significantly lower than the total consumption of the corresponding control group. This was a most unexpected result and because the next higher concentration did not produce a similar significant result, this observation was most likely a statistical anomaly.

The proton (H^+) is the principal sour gustatory stimulus, and sour taste reception relies primarily on the proton concentration (Settle et al., 1986). However, responses to the sour tastes of acids and bases also vary depending on the species of birds, the ages of birds, and the types of acids (Fuerst and Kare, 1962; El Boushy et al., 1989). Birds appear to be more sensitive to inorganic acids than to organic acids, and chicks appear to be more sensitive than adults (Fuerst and Kare, 1962; El Boushy et al., 1989). Adult cockatiels in our study were offered buffered citric acid solutions with a constant molarity (0.05 mol l^{-1}) but differing pH. Consumption patterns were changed at pH 5.5 when placed on the preferred side and 5.0 when placed on the non-preferred side. Harriman and Fry (1990) find a significant relationship between decreasing pH and decreasing solution acceptance with citric acid for the pH range 4.0 to 1.5 in Common ravens (1990). Additionally, chickens (*Gallus domesticus*) reject a 2% (approximately 0.10 mol l^{-1}, pH 2.3) or greater aqueous citric acid solution (El Boushy et al., 1989). In another study, chickens rejected only solutions with a pH less than 2.0 (Fuerst and Kare, 1962). When compared to these studies, our results, by showing a change in consumption at 0.05 mol l^{-1} and pH 5.5, suggested that the ability to taste organic acids in cockatiels is more acute than that of chickens.

For cockatiels, the consumption of 0.36 mol l^{-1} sucrose was significantly less than that of purified water for several consumption parameters. A significant inverse relationship between sucrose solution concentration and consumption levels results when common ravens are tested for sucrose. A decrease in sucrose consumption does not occur until a 1.00-mol l^{-1} solution is offered (Harriman and Fry, 1990). Kare and Mason (1986) report that parrots and budgerigars, among other birds, choose sugar solutions over water. Harriman and Milner (1969) report that Japanese quail (*Coturnix coturnix japonica*) consume significantly more of a 0.30-mol l^{-1} sucrose solution than distilled water. Rhode Island Red-Barred Plymouth Rock crossbreds and Brown Leghorns prefer a 10% (0.292 mol l^{-1}) and a 5% (0.146 mol l^{-1}) sucrose solution, respectively (Kare et al., 1957; Gentle, 1972). However, our data supported the findings that when fed a complete diet, many avian species do not prefer sugar solutions (El Boushy et al., 1989).

5. Conclusion

In all cases, increasing concentration eventually resulted in decreased, rather than increased, intake. No concentrations were found to be significantly attractive. Possibly, this is due to the novel qualities of the tastes. Before these experiments, birds only had access to deionized water for drinking. When a new, unexpected compound was added at a level that could be tasted, the birds switched to the other side seeking and preferring the familiar water-only option.

In summary, cockatiels can distinguish between water and 0.16 mol l^{-1} sodium chloride, 0.36 mol l^{-1} sucrose, or a pH 5.5 citric acid buffer. For citric acid and sodium chloride, the threshold was more powerfully detected when the test solution is placed on the preferred side. The sucrose threshold, however, was more powerfully detected when placed on the non-preferred side. For all tested compounds and concentrations, significant changes were found only to be repulsive, and not attractive.

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