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Anim Cogn. Author manuscript; available in PMC 2015 March 01.

Published in final edited form as:
Anim Cogn. 2014 March ; 17(2): 177–183. doi:10.1007/s10071-013-0650-y.

Defining Reward Value by Cross-Modal Scaling

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Abstract

Researchers in comparative psychology often use different food rewards in their studies, with food values defined by a pre-experimental preference test. While this technique rank orders food values, it provides limited information about value differences because preferences may reflect not only value differences, but also the degree to which one good may "substitute" for another (e.g., one food may substitute well for another food, but neither substitutes well for water). We propose scaling the value of food pairs by a third food that is less substitutable for either food offered in preference tests (cross-modal scaling). Here, Cebus monkeys chose between four pairwise alternatives: fruits A vs. B; cereal amount X vs. fruit A and cereal amount Y vs. fruit B where X and Y were adjusted to produce indifference between each cereal amount and each fruit; and cereal amounts X vs. Y. When choice was between perfect substitutes (different cereal amounts), preferences were nearly absolute; so too when choice was between close substitutes (fruits); however, when choice was between fruits and cereal amounts, preferences were more modest and less likely due to substitutability. These results suggest that scaling between-good value differences in terms of a third, less-substitutable good may be better than simple preference tests in defining between-good value differences.

Keywords

choice; reward value; substitutability; cross-modal scaling; economics; capuchin; monkey; Cebus apella

Introduction

Operant-oriented researchers have spent many years trying to measure reinforcer value. Among the measures that have been advanced are response rate (Hull, 1943; Skinner, 1932a, 1932b, 1938), preference (Herrnstein, 1970), behavioral output (Hodos, 1961), economic demand curves (Hursh & Silberberg, 2008), and the sensitivity of behavior to changes in dimensions of reinforcement (Nevin, 1992). The persistence of this effort and the variety of measures advanced speak to both the importance of this measure and to the difficulty in constructing a scale of value.

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Interestingly, the concern over how to measure reinforcer value has, on the whole, been largely ignored by animal researchers with a more cognitive focus. This oversight may be less consequential in those studies in which a single reinforcer is used and the conditions of its delivery are altered across conditions. However, many experiments use qualitatively different reinforcers, looking at how behavior changes as a function of their relative value in a single condition. In these studies, there is often a pre-experimental test of preference among these different foods so that a rank order of value may be constructed. What is lacking in such a value scale is the answer to what learning theorists have considered the next question to ask: Just how much do these foods differ in value[1]?

In this report we argue that the interpretations given to outcomes where qualitatively different foods are used may be compromised if each food's value is defined solely in terms of preference. To make this claim explicit, we will discuss examples of how ignorance of differences in value may affect the conclusions reached.

Evans and Beran (2007) assessed delay of gratification in macaques by first demonstrating in a choice test that their subjects preferred grape to celery, and then offering the subjects a choice between celery, which was immediately available, and grape, which was available only after a delay (Experiment 2). Across trials the duration of the delay was adjusted until approximate indifference between alternatives was achieved. While there were individual differences, it was noted that by tolerating delays of two minutes, a minority of macaques approached the levels of self-control seen in apes (Beran, Savage-Rumbaugh, Pate, & Rumbaugh, 1999).

While this observation is correct, acknowledging this approximation in self-control performances between some macaques and apes may be problematic because the apes received different food alternatives for their choices. It is therefore possible that differences in tolerating delays between macaques and apes were due to differences in reward value since the value difference between grape and celery for macaques may have been greater than between banana and carrot for apes. This greater value difference might possibly have increased a natively lower indifference point in the macaque self-control test. Consequently, one may want to qualify any statement about occasions when these two species have comparable tolerance levels for delay of reinforcement.

A second example comes from a study on inequity aversion by Brosnan and de Waal (2003). In this study, two female capuchins in adjacent cages exchanged tokens with an experimenter for cucumber or grape. If the first subject exchanged for a cucumber, the second subject also exchanged for cucumber. However, if subsequently the first subject exchanged for a grape, the previously acceptable cucumber was now rejected by the second subject. Given that a pre-experimental choice test showed that capuchins preferred grape to cucumber, Brosnan and de Waal explained the second subject's rejection of the cucumber as indicating capuchins' recognition of inequity between their own rewards and those of another.

This work generated considerable research activity among researchers who wished to flesh out the processes underlying this result. In pursuit of this goal, procedures akin to Brosnan and de Waal's (2003) were often repeated, but surprisingly, the very effect under study proved labile—that is, sometimes inequity aversion emerged (e.g., group-housed female capuchins in Brosnan & de Waal, 2003; pair- and group-housed chimpanzees in Brosnan,

[1]Scaling the value of two foods, A and B, may be done relatively (A/B or A/(A + B)) or in terms of differences (A - B). Given the absence of evidence resolving how value comparisons should be scaled (e.g., see Birnbaum, 1980), we refer to value comparisons in both ways, with language selection governed by context of discussion, and not by endorsement of a particular dependent variable.

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Schiff, & de Waal, 2005; group-housed capuchins in van Wolkenten, Brosnan, & de Waal, 2007), but sometimes it did not (e.g., group-housed apes in Bräuer, Call & Tomasello, 2006; group-housed male capuchins from Brosnan & de Waal, 2003; long-term social group of chimpanzees in Brosnan et al., 2005; group-housed capuchins in Dindo & de Waal, 2007; pair-housed female capuchins in Fontenot, Watson, Roberts, & Miller, 2007; group-housed female capuchins in Silberberg, Crescimbene, Addessi, Anderson & Visalberghi, 2009). In consequence, the apparent unreliability of inequity-aversion effects has led Wynne and Bolhuis (2008) to deny the existence of this phenomenon.

However, there is another explanation for these disparate outcomes; in studies where inequity aversion was found, the value difference between the preferred and non-preferred food may have been large and where inequity aversion failed to emerge, the difference may have been small. For example, perhaps Brosnan and de Waal (2003) found inequity aversion in female capuchins while Silberberg et al. (2009) did not because the value difference between grape and cucumber in the former study exceeded the value difference between pine nut and sunflower in the latter.

Implication of examples

In two examples, we illustrated that: (a) cross-species comparisons of capacity for self-control could be potentially compromised by unawareness about differences in the reinforcing value of qualitatively different foods; and (b) the unreliability of inequity aversion across studies may be more apparent than real, a consequence again of lack of knowledge about the relative value (or value difference) of different foods used in an experimental test. We do not argue for dismissing phylogenetic comparisons of delay of gratification; nor do we argue that failures to find inequity aversion are due to using food types that do not differ enough in value. Instead, our purpose is to underscore that the proper scaling of reinforcer value should be a concern of all comparative-psychology researchers whose methods use foods that differ in kind.

How then can reinforcer value be defined? One idea is that we continue to use preference data to measure reinforcer value differences with greater preference for one reinforcer indicating greater value difference. For example, if a monkey prefers grape to cucumber in a ratio of 2 to 1, and grape to sunflower in a ratio of 3 to 1, then it seems that the grape-sunflower value difference should exceed the grape-cucumber value difference. Unfortunately, determination of value differences may not be this simple because different foods in a food pair may differ in the degree to which one can substitute for the other (Hursh, 1980). To illustrate subtitutability, consider choice between two close substitutes (two goods that are very similar): identically priced automobiles that differ in that one has vinyl seats and the other has leather seats. When given a choice between cars, the car with leather might be preferred by consumers over the car with vinyl at, say, a 10-to-1 ratio, an outcome that suggests a huge value difference for those who use preference as an index of value. However, if a minor additional change is made in the car with vinyl seats—say, a sunroof is added—the initial preference for the car with leather seats may be reversed. We can therefore say that even though the car with leather seats is preferred over the car with vinyl seats, these goods may not differ greatly in value because minor alterations in their attributes (e.g., adding a sunroof) may have a large effect on preference. On the other hand, when given the choice between a car and, say, a motor boat, we may see the same 10-to-1 ratio in consumer demand, but adding a sunroof to the car might not affect this preference because the car and the motor boat share fewer attributes, an outcome that results in lower substitutability. Therefore, the results of a simple preference test (i.e., which car do you want?) cannot indicate value unless you have some means of judging the impact of between-good substitutability on the measure used.

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This idea can then be applied to comparative-psychology studies. Silberberg et al. (2009) chose pine nut and sunflower seeds, both seeds, as choice alternatives in their inequity-aversion test while Brosnan and de Waal (2003) used grape, a fruit, and cucumber, a vegetable, as pairwise alternatives in their demonstration of this effect. For both studies, pre-experimental preferences for the preferred food approximated 90%, which Silberberg et al. used to claim comparability in value between their pairwise alternatives and those of Brosnan and de Waal. But what if this preference is due more to differences in substitutability between foods in these two studies? Given that both pine nuts and sunflower seeds are seeds, and share the attributes that make them seeds, the preference for pine nut found by Silberberg et al. may be due to pine nuts' high substitutability with sunflower seeds rather than a large between-food difference in value—or as applied to the example above, pine nuts and sunflower seeds may be equivalent to a car with leather seats vs. a car with vinyl seats. By contrast, Brosnan and de Waal used a vegetable and a fruit, which may differ more from each other in terms of their attributes, and as a result, be less substitutable. If so, the fact that both studies' initial preference levels were at 90% offers no assurance that the reinforcers had similar value differences.

How then should value differences be determined? An economist might define value by the sensitivity of demand for a good to changes in price. If increases in price lead to only small reductions in demand, the economist would label that good as high value. For example, if the price of all foods in grocery stores doubled, it seems probable that humans would still purchase food in largely the same caloric amounts as before so that they could defend their body weights. Such inelasticity in demand would suggest food is of high value to humans. On the other hand, if the price of going to the movies were to double, demand for movie attendance might drop considerably. Such elasticity in demand for seeing movies would suggest that, at least when compared to food, seeing movies is of lower value. By comparing how demand changes with price, it seems possible to get some understanding of how two goods differ in value (see Hursh & Silberberg, 2008).

Some analysts have applied this approach with some success. Price has been defined in terms of the number of responses necessary to produce a reinforcer. It is then measured how demand for that reinforcer changes with price. Unfortunately, it may be difficult for comparative researchers to adopt these techniques to their current designs. For this reason, we propose an alternative scheme that can be easily incorporated within conventional their methods, and may be useful in scaling the values of two different foods in terms of a common metric, in this case, a third food.

Scaling two foods by a third food

We propose to scale the value of two foods in terms of a third, less-substitutable food, and then use amounts of this third food to quantify the value ratio or difference of the two other foods. For example, imagine that a session is composed of four different pairwise choice trials: fruit A vs. fruit B, fruit A vs. X cereal pieces, fruit B vs. Y cereal pieces, and X cereal pieces vs. Y cereal pieces. Over sessions, the number of cereal pieces (X and Y) is titrated until approximate indifference is obtained between cereal pieces and each fruit alternative. We would now be able to scale the value difference between fruit A and fruit B in terms of cereal pieces. If it takes four cereal pieces to make a subject indifferent between it and fruit A, and one piece to make a subject indifferent between it and fruit B, then we can assign a value ratio of four (or a value difference of three) to the pairwise presentation of fruits A and B, respectively.

Given that only three trial types (fruits A vs. B, fruit A vs. X cereal pieces, fruit B vs. Y cereal pieces) are needed to produce this scale, what is the purpose of the fourth trial type (X vs. Y cereal pieces)? It is included as a test of the substitutability thesis which we used to

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dismiss “degree of preference” as an indicator of reinforcer value. If that thesis is correct, it should be the case that the foods that are perfect substitutes (X vs. Y amounts of the same cereal) should show the strongest preferences, a result akin to that seen in the car example earlier. This prediction follows from the fact that in terms of all attributes but one, the number of food pieces, these alternatives are identical; and given that generally more is better than less, preference for the larger alternative should be high. These preferences should be followed by fruit preferences which share the characteristics that make them fruits, but in other regards differ. Finally, the smallest preferences should appear for the foods that share the fewest characteristics, fruits vs. grains (i.e., cereal). In consequence, this design holds the promise of not only scaling foods in terms of a third food, but also providing empirical support for the thesis that such an approach may be necessary because differences in substitutability among foods affect preferences independently of the value of the foods being evaluated.

One criticism that can be anticipated of this scaling scheme is that assessing preference between a *varying number* of cereal pieces and a *single piece* of fruit confounds food quantity with food quality. However, we are not comparing the value of two goods which just vary in number and quality; rather, we compare two goods that vary in many attributes, with “number” being one of many attributes in which they differ (they also differ in position [left or right], sweetness, texture, calories, etc.). Because the “value” of each good is the sum of all component values, the number and composition of each individual attributes are less critical. Rather, when two goods are offered, their aggregate relative value can be defined by subject preference.

Method

Subjects

Seven adult male tufted capuchins (Cebus apella) housed in indoor cages (1.78 m × 0.76 m × 1.85 m) at the NICHD Laboratory of Comparative Ethology in Poolesville, MD, served as subjects. Four monkeys were pair-housed (Jaws and Icarus, Shane and Lenny), and three monkeys were housed as a small group (Hotrod, Jr. Mint, and Mr. Goodbar). All subjects had free access to water and food biscuits. Testing occurred after morning rations of biscuits and enrichment, but prior to receipt of their afternoon food rations of biscuits and treats. For testing, each monkey was separated from their cage-mate by means of wire mesh or plastic partitions. Cage-mates remained visible throughout the session. There was a 7.5-cm opening between successive bars in the front of the cage that was sufficient to permit the subject to reach out of the cage for food.

Procedure

Each session began by placing two food arrays 38 cm apart on a 33- by 40.5-cm plastic board in the presence of the subject and were then offered by advancing the board to within the subject's reach. A choice consisted of reaching with one hand for one of the two food arrays. In those cases where the subject extended both arms through the cage, the food board was immediately moved out of reach. Successive trials were separated by a 30-s intertrial interval during which any food array taken was replaced and the positions of the arrays on the board were rearranged, if necessary, according to a predetermined pseudorandom sequence. In pretesting, subjects chose in five kinds of trials: fruit A vs. fruit B, fruit A vs. 1 or 5 cereal grains, and fruit B vs. 1 or 5 cereal grains. Each fruit piece was cut to be about the size of a blueberry. Subjects were advanced to the main test when a combination of cereal and fruits was found such that neither fruit was preferred absolutely over the other, and that both fruits were preferred to one piece of cereal, but neither fruit was preferred over five pieces of cereal. If a particular combination of food arrays failed to produce the desired

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outcome in a session, the array was changed until a qualifying combination was identified. Each pretesting session lasted for 20 trials, with four trials assigned to each choice arrangement. Pretesting ended when a particular combination of foods met the choice criterion described above. Since we failed to find a suitable combination of fruit and cereal for Mr. Goodbar, he was removed from the study.

Once subjects moved to testing, sessions consisted of twenty choice trials. One session was conducted per day, five days per week unless scheduling conflicted with other studies. Each session included four types of trials in random order, with each type of trial representing a different choice: fruit A vs. fruit B, fruit A vs. X amount of cereal, fruit B vs. Y amount of cereal, and X amount of cereal vs. Y amount of cereal. Each choice was presented five times per session. X and Y (the amounts of cereal) were increased by one piece per session from an initial level of one cereal piece in the first session until a criterion indifference point was reached against the two fruits. If an indifference point could not be reached, half- and quarter-pieces of cereal were used to adjust the amount of cereal. Each monkey underwent as many sessions as needed to reach this indifference point. Choice was considered indifferent if, over two sessions, the choice ratio between the cereal amounts and the average for both fruits fell between 4:10 and 6:10.

Results

Table 1 presents for each subject the choice ratios from the last ten trials from the four trials types used in this study: fruit A vs. fruit B, where A is the preferred fruit type; the cereal amounts used to achieve indifference between choice of cereal and fruit; and the cereal amounts X vs. Y, where X and Y were the number of cereal pieces needed to produce indifference between them and fruits A and B, respectively.

Figure 1 presents the relative-choice data for the three types of trials in Table 1: the preferred fruit (A) vs. the unpreferred fruit (B); cereal amount X (which was sufficient to achieve indifference to fruit A) divided by cereal amount Y (which was sufficient to achieve indifference with fruit B); and cereal amount X vs. Y. As shown in Table 1 and Figure 1, choice between the qualitatively perfect substitutes of cereal amounts X vs. Y resulted in a near-absolute preference for the larger amount. Choice between the close substitutes of fruits A and B led to a smaller preference for the preferred fruit. Finally, with the presumably lower substitutability of cereal vs. fruits, preferences for the preferred fruit scaled in relative amounts of cereal were lower still. Based on two-tailed paired two-sample t-tests, the choice difference between fruit A vs. fruit B and cereal amounts equated in choice to these goods was statistically significant ($t(5) = 3$, $p = .03$); so too was the difference in preference for cereals X vs. Y when compared to preference scaled by cereals equated with each fruit type ($t(5) = 4.97$, $p < .01$); however, the greater preference seen when the perfect substitutes of cereals X vs. Y were compared to those from the close substitutes of fruits A vs. B was not significant ($t(5) = 0.83$, $p = .44$).

Figure 2 presents the individual-subject performances when preferences between fruits are defined as fruit A vs. fruit B as opposed to defining this preference in terms of cereal amounts that had been adjusted to produce indifference between a given cereal amount and a given fruit. This graph shows that preferences that are often absolute when fruits are compared against each other tend not to be so when scaled in terms of cereal equivalents.

Discussion

One of several factors complicating the determination of the relative reinforcing value of two or more foods by a preference test is that between-good interactions may affect the

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outcome. Some foods—those that share many characteristics--may be sensitive to asymmetric constraint imposed by, say, price or effort. For example, small changes in the price of brown vs. white eggs are likely to produce large changes in preference because these goods are highly substitutable. If, as often happens in experiments with nonhuman primates, the relative value of foods is only defined by a preference test in which the "price" of receipt of both foods is the same (e.g., the effort in reaching for each food is the same), preferences that may appear large may in fact be small when between-good prices differ even a little.

This conclusion is consistent with this report's findings. As shown in Table 1 and Figure 2, monkey preferences between fruits that differ in type may not just be large, but are often absolute. Nevertheless, when scaled cross-modally in terms of another type of food, in this case cereal, large differences tend to become small. As noted in the Introduction, this approach of cross-modal scaling of value may prove useful in explaining differences in outcome across experiments in the study of phenomena such as inequity aversion or delay of gratification. Quite possibly, a large difference in value seen from a preference test on highly substitutable foods may mask an alternate reality—that these goods do not differ much in terms of value.

In this study, we measured the value of two fruits by scaling them in terms of cereal, a third food that was less substitutable for either fruit than those fruits were for each other (see Figure 1). This design—reduced substitutability in terms of the yardstick used to measure value—was requisite for its use as our measure, for if the third food rivaled the comparison foods in substitutability, the absolute preferences seen with fruits in this study would also be seen when they were scaled against this highly substitutable third food.

Ideally, the scaling food would be orthogonal to the foods being measured in terms of substitutability. For example, perhaps the reinforcing value of "time being groomed" has little in common with the reinforcing value of food, and therefore the value of two foods could be scaled in terms of time spent grooming. Although such a scale would be more desirable than the one we used, namely cereal which to an extent is substitutable for fruit (both are foods), the implementation of grooming as a reward may be difficult to arrange experimentally. Scaling value in terms of cereal is therefore a compromise between rigor and practicality. For experimental designs that rely on differences in reinforcer value, this method may be used with relative ease and should take no more than a few weeks to complete. Although cross-modal scaling of foods is burdensome when compared to a simple choice test, being able to control for subject or species differnces in terms of reinforcer value should outweigh the added effort this technique imposes.

The present report provides a cross-modal scale of fruit pairs where cereal served as currency—that is, the measure of value. The technique used seems suitable for use in a wide range of experimental studies in which two or more foods are used. An alternative approach to determine value of foods would be to use monkeys trained to exchange tokens in return for food. The Law of Demand states that as the price of a food is raised (e.g., increasing the number of tokens from, say, two to three to "buy" a piece of food), demand (the number of food pieces purchased) should decrease. If the cost of a food is varied over a wide enough range, it would be possible to define a demand curve in which the quantity purchased varies as a function of price. Demand for high-value foods should decrease more slowly than for low-value goods. By using models that measure the rate of decline in demand with increasing price (e.g., Hursh & Silberberg, 2008), it may be possible to construct a scale of value for different foods with even greater specificity.

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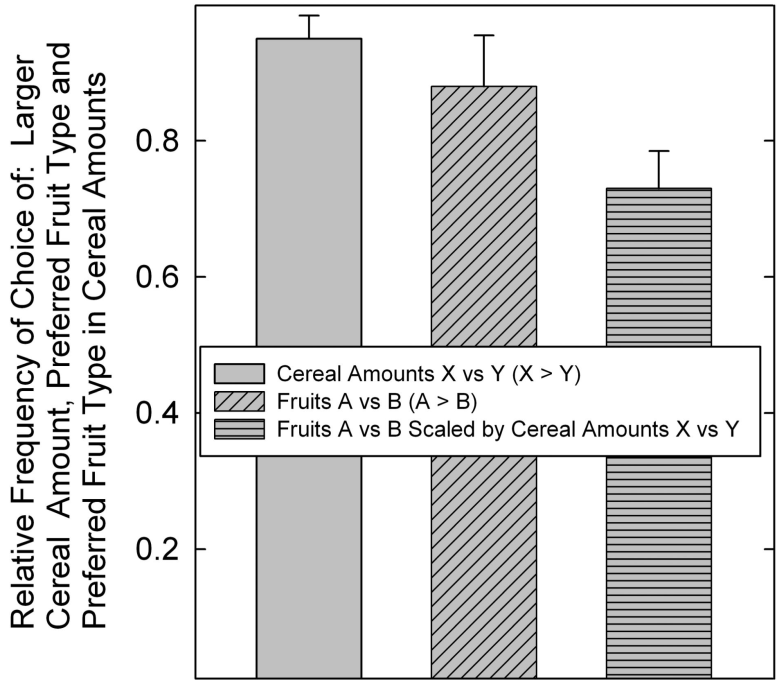

Figure 1.

Mean preference for three types of choice trials: (1) cereal vs. cereal, where the amount offered in each alternative equaled the amounts necessary to produce indifference for each type of fruit; (2) fruit A vs. fruit B; and (3) fruits A vs. B scaled in terms of cereal amounts. The “T” atop each bar defines one standard error above the mean.

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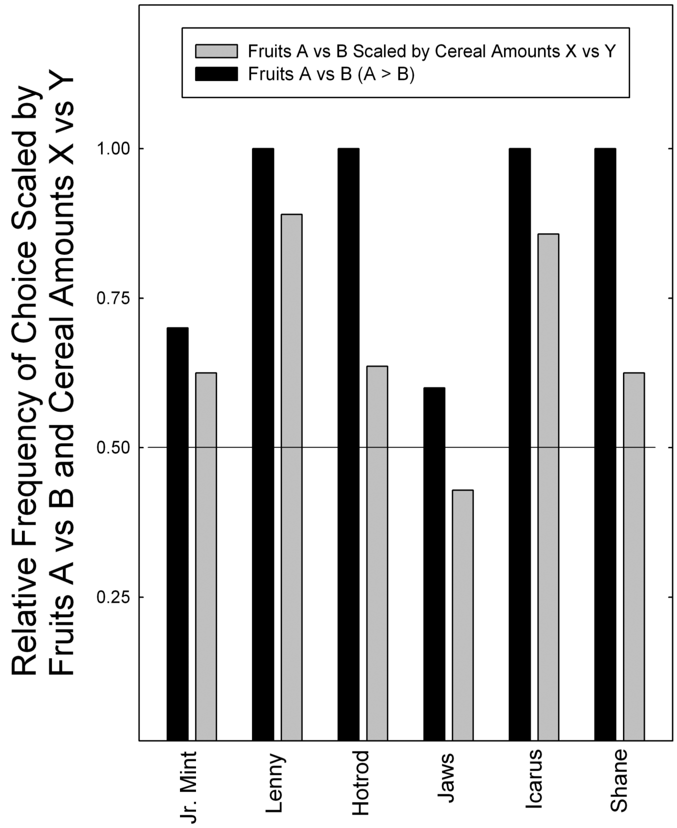

Figure 2.

Individual-subject preference for the preferred fruit type based either on relative frequency of choice of the preferred fruit, or these fruits scaled in terms of cereal amounts.

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Table 1

Subjects, foods offered in choice, and choice ratios obtained over 10 trials

Subject	Choice Alternatives	Choice Ratio
Junior Mint	apple : grape	3:7
	apple : 1.5 Honey Nut Cheerios	5:5
	grape : 2.5 Honey Nut Cheerios	5:5
	1.5 Honey Nut Cheerios : 2.5 Honey Nut Cheerios	0:10
Lenny	apple : grape	0:10
	apple : 0.25 Fruit Loops	6:4
	Grape : 2 Fruit Loops	6:4
	0.25 Fruit Loops : 2 Fruit Loops	0:10
Hotrod	apple : banana	10:0
	apple : 1.75 Apple Jacks	6:4
	banana : 1 Apple Jacks	4:6
	1.75 Apple Jacks : 1 Apple Jacks	8:2
Jaws	blueberry : banana	4:6
	blueberry : 2 Cheerios	4:6
	banana : 1.5 Cheerios	5:5
	2 Cheerios : 1.5 Cheerios	9:1
Icarus	apple : banana	10:0
	apple : 3 Honey Nut Cheerios	5:5
	banana : 0.5 Honey Nut Cheerios	5:5
	3 Honey Nut Cheerios : 0.5 Honey Nut Cheerios	10:0
Shane	apple : grape	0:10
	apple : 3 Honey Nut Cheerios	5:5
	grape : 5 Honey Nut Cheerios	7:3
	3 Honey Nut Cheerios : 5 Honey Nut Cheerios	0:10