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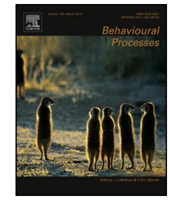

Reinforcer magnitude and demand under fixed-ratio schedules with domestic hens

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ABSTRACT

This study compared three methods of normalizing demand functions to allow comparison of demand for different commodities and examined how varying reinforcer magnitudes affected these analyses. Hens responded under fixed-ratio schedules in 40-min sessions with response requirement doubling each session and with 2-s, 8-s, and 12-s access to wheat. Over the smaller fixed ratios overall response rates generally increased and were higher the shorter the magazine duration. The logarithms of the number of reinforcers obtained (consumption) and the fixed ratio (price) were well fitted by curvilinear demand functions (Hursh et al., 1988. Journal of the Experimental Analysis of Behavior 50, 419–440) that were inelastic (*b* negative) over small fixed-ratios. The fixed ratio with maximal response rate (P_{max}) increased, and the rate of change of elasticity (*a*) and initial consumption (*L*) decreased with increased magazine duration. Normalizing consumption using measures of preference for various magazine durations (3-s vs. 3-s, 2-s vs. 8-s, and 2-s vs. 12-s), obtained using concurrent schedules, gave useful results as it removed the differences in *L*. Normalizing consumption and price (Hursh and Winger, 1995. Journal of the Experimental Analysis of Behavior 64, 373–384) unified the data functions as intended by that analysis. The exponential function (Hursh and Silberberg, 2008. Psychological Review, 115, 186–198) gave an essential value that increased (i.e., α decreased significantly) as magazine duration decreased. This was not as predicted, since α should be constant over variations in magazine duration, but is similar to previous findings using a similar procedure with different food qualities (hens) and food quantities (rats).

1. Introduction

Knowing the aspects of an animal's world that are important to that animal is essential to maximize its welfare and to predict its future behavior. Several different methodologies can be used to gain information about the importance of a given commodity. For example, assessing the degree to which an animal selects one commodity over another indexes the relative value of the two commodities to that animal. Several such procedures, termed preference assessments, were described by Sumpter et al. (2002). Normally they involve the animal making a response to gain access to one of two or more commodities. The response may be simply moving from one location to another, or selecting one arm of a maze or operating a manipulandum, such as a key or lever. Preference is assessed by the degree to which an alternative is selected over the others, e.g., the proportion of choices of or relative time allocated to that alternative. Measures of preference obtained in this way are always relative to the commodities on offer and the results are taken to be the animals' preferences between the commodities on offer at that time, that is, they are measures of the relative values of the commodities. Such procedures allow direct comparison of the commodities and it is possible to conclude which is of more importance to the animal in that context.

Another methodology that provides information on the importance of commodities to animals comes from applications of consumer demand theory (Dawkins, 1983). In one such procedure the effort (or price) required to gain access to a commodity is varied and the way consumption changes is examined. In this procedure, termed own-price demand (Green and Freed, 1998), the relation between the amount of the commodity consumed at each price and price is taken to be a description of animal's demand for that commodity and is known as a demand function (Hursh, 1984). In basic research with animals, price is typically operationalized as the number of responses required to produce a reinforcer (e.g., fixed-ratio (FR) size) and consumption as the number of reinforcers earned.

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Hursh et al. (1988) proposed that demand functions could be described using the equation:

$$\ln Q = \ln L + b(\ln P) - aP, \tag{1}$$

where Q refers to total consumption, P denotes price, and L, a, and b are free parameters. The parameter L estimates the initial level of consumption obtained at the minimal price and reflects the height of the demand function above the origin. When consumption is measured on a common scale, the larger the L value the more is consumed at minimal price. The parameters a (the rate of change in the slope of the function across price increases) and b (the initial slope of the function) reflect aspects of the elasticity of the demand function. Both a and b are required to describe the elasticity of the function and if, for example, two demand functions have very different b values, then the a values cannot be sensibly compared. When a function is inelastic (i.e., with slope less steep than −1) over low prices but changes to being elastic (i.e., falling with a slope steeper than −1) as price increases, then a and b can be used to find the price associated with maximal response output. This is the price at which demand changes from inelastic to elastic and is termed P_{max} (Hursh and Winger, 1995), which is calculated as:

$$P_{max} = \frac{(1+b)}{a}. \tag{2}$$

The higher the price at which demand changes from inelastic to elastic, the larger the value of P_{max}. Equations (1 and 2) have proven to be useful in describing the data from many research studies (e.g., Foster et al., 1997; Foltin, 1992; Sumpter et al., 1999; Hursh and Winger, 1995).

Because a demand analysis encompasses the effects of changing price or effort, it can be viewed as a more general measure of the value of a commodity than preference estimates alone. For example, one commodity might be preferred over another or might be preferred similarly to another when little effort is required to obtain either but the relative preference might change when the amount of effort required to obtain the commodities changes. Such a relation is evident in a study by Williams and Woods (2000), in which monkeys preferred a 0% ethanol solution (tap water) to a 32% ethanol solution under an FR 4 schedule, but preferred the 32% ethanol solution at FR values of 32 and 64. To obtain the same total "value" in demand sessions with each of two commodities if one was relatively more preferred than the other in a preference assessment, the animal would need to obtain more of the less preferred than of the more preferred commodity. Therefore, at low prices the preference between the commodities may result in consumption of the less preferred commodity (i.e., the number of reinforcers earned) in a session being higher than consumption of the more preferred commodity. If price were increased, then the animal might maintain this difference or responding might reduce for the less preferred commodity more rapidly, resulting in a more elastic demand function. In the latter case, where b is similar for two commodities, a would be larger (i.e., a higher rate of change of elasticity) and P_{max} smaller (i.e., it would maintain behavior to a lower price) for the less preferred commodity. Such an analysis involves comparisons of the demand functions from the different commodities, a point made by Williams and Woods (2000).

Comparison of demand functions requires that consumption of the various commodities be measured on a common scale. To do so, Hursh and Winger (1995) suggested that, when the aim was to compare demand for different commodities such as different drugs, the measure of consumption of the various drugs could be normalized. Their normalization involved converting the consumption measures to a percentage of consumption at the lowest price, thus giving all demand functions an initial consumption value of 100. They normalized the price, converting this to the price per unit of normalized consumption. Madden et al. (2007a,b) applied this normalization to data from prior studies (e.g., Ko et al., 2002; Winger et al., 2002) to compare the relative reinforcing efficacy of various drugs. The ranking of reinforcing efficacy that resulted was consistent with that predicted by other means.

The approach suggested by Hursh and Winger (1995) relies on normalizing using the initial level of consumption obtained in generating the demand function. Foster et al. (2009) offered another strategy for normalization. They suggested that it should be possible to use a preference measure to normalize consumption data, a strategy they called "preference-adjusted demand." This strategy involved comparing commodities using a concurrent-schedule choice procedure (see Davison and McCarthy, 1988) and then applying the resulting preference measure to normalize the demand data. The suggested preference measure was based on the generalised matching equation (Baum, 1974, 1979). Matthews and Temple (1979) previously demonstrated that the following version of that equation could be used to assess bias or preference resulting from qualitatively different reinforcers:

$$\log\left(\frac{P_1}{P_2}\right) = a_s \log\left(\frac{R_1}{R_2}\right) + \log b_c + \log q \tag{3}$$

where P_1 and P_2 are the numbers of responses to the two concurrently available schedules, R_1 and R_2 are the number of reinforcers obtained under the two schedules, a_s reflects the sensitivity of behavior to changes in reinforcement rate, $\log b_c$ quantifies the bias (i.e., the tendency to respond more under one schedule than under the other) resulting from factors other than reinforcer differences, and $\log q$ measures bias resulting from differences between the two reinforcers. $\text{Log}\, q$ is taken as a measure of the preference for one reinforcer over the other. The total bias, $\log b_c + \log q$, is often termed $\log c$. When the two schedules deliver reinforcers equally often, then R_1 will equal R_2 and, as $\log(R_1/R_2)$ will equal 0, the equation reduces to:

$$\log\left(\frac{P_1}{P_2}\right) = \log b_c + \log q = \log c \tag{4}$$

As Sumpter et al. (2002) pointed out, the value of $\log b_c$, or preference, can be found using the same reinforcer on both schedules (so that $\log q$ equals 0). When different reinforcers are arranged under the two schedules, with equal reinforcer rates, then a measure of $\log c$ (i.e., $\log b_c + \log q$) is obtained. Subtracting $\log b_c$ from this value gives the value of $\log q$ alone.

Foster et al. (2009) used this process to assess hens' preference among three foods, wheat (W), puffed wheat (PW), and honey-puffed wheat (HPW), by pairing W with W, W with PW, and W with HPW. They found W was preferred to HPW and PW, and that PW was least preferred. They also used single FR schedules with each of the three foods and increased the number of responses required to gain access to a food over sessions (i.e., increasing FR schedules). This procedure assessed demand for each of the three foods when presented alone. The analyses proposed by Hursh et al. (1988) and Hursh and Winger (1995) were then compared with that from a preference-adjusted demand analysis based on the Hursh et al. equation (i.e., using the preference data from the concurrent schedule phase to normalize consumption).

While the functions generated by all three analyses fitted the data well, the relations between the various parameters and preference were not clear. The unmodified data (Hursh et al., 1988) resulted, paradoxically, in the lowest initial consumption (measured as number of reinforcers obtained) for the most preferred food. In line with the preference data, however, the most preferred food had the highest P_{max} value. Hursh and Winger's (1995) analysis necessarily reduced the initial consumption differences between the foods, and this normalization resulted in the least preferred food having the highest P_{max} value. Normalizing the data in this