

# The use of operant technology to measure behavioral priorities in captive animals

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Addressing the behavioral priorities of captive animals and the development of practical, objective measures of the value of environmental resources is a principal objective of animal welfare science. In theory, consumer demand approaches derived from human microeconomics should provide valid measures of the value of environmental resources. In practice, however, a number of empirical and theoretical problems have rendered these measures difficult to interpret in studies with animals. A common approach has been to impose a cost on access to resources and to use time with each resource as a measure of consumption to construct demand curves. This can be recorded easily by automatic means, but in a number of studies, it has been found that animals compensate for increased cost of access with longer visit time. Furthermore, direct observation of the test animals' behavior has shown that resource interaction is more intense once the animals have overcome higher costs. As a consequence, measures based on time with the resource may underestimate resource consumption at higher access costs, and demand curves derived from these measures may not be a true reflection of the value of different resources. An alternative approach to demand curves is *reservation price*, which is the maximum price individual animals are prepared to pay to gain access to resources. In studies using this approach, farmed mink (*Mustela vison*) paid higher prices for food and swimming water than for resources such as tunnels, water bowls, pet toys, and empty compartments. This indicates that the mink placed a higher value on food and swimming water than on other resources.

## Measuring Behavioral Needs

An important development in animal welfare science has been the use of consumer demand approaches derived from human microeconomics to assess the value of resources to captive animals (Dawkins, 1983; Lea, 1978; Rachlin, Green, Kagel, & Battalio, 1976). Two measures of behavioral elasticity have been recommended—*elasticity of demand* and *income elasticity* (Dawkins, 1990). For elasticity of demand, the price of commodities or environmental resources is varied, and, for income elasticity, the price of environmental resources is fixed, but the animal's income (in terms of time or energy budgets) is varied. With both techniques animals defend consumption of important resources but not consumption of luxuries, so it is possible to rank resources in terms of their importance to the animal (Dawkins, 1990; Mason, McFarland, & Garner, 1998). Although, there have been a small

number of studies of income elasticity (e.g., Cooper & Mason, 1997a; Dawkins, 1983), the majority of studies in animal economics have used demand elasticity to compare the value of resources, so this paper primarily focuses on studies of demand elasticity.

The elasticity of demand ( $e$ ) of a resource or commodity is derived by plotting its consumption against its price and calculating the rate of decline in consumption per unit increase in cost (Dawkins, 1990; Lea, 1978). This can be calculated with the use of calculus, but where resources have constant elasticity, the elasticity is mathematically equal to the absolute value of the typically negative slope of the plot of log consumption against log price (Kagel, Battalio, & Green, 1995; Lea, 1978; Matthews & Ladewig, 1994). For example, if each increase in unit price halves the consumption of the resource, then  $e = 2$ . Conventionally, in animal studies, elasticity is assumed to be constant (e.g., Matthews & Ladewig, 1994; Sherwin & Nicol, 1996), and consequently, the slopes of these log-log plots are used to compare the values of different resources. Some authors have adopted a cutoff of  $e = 1.0$  to discriminate between inelastic necessities ( $0 < e < 1$ ) and elastic luxuries ( $e > 1$ ) (e.g., Gunnarsson, Matthews, Foster, & Temple, 2000; Matthews & Ladewig 1994), whereas others have ranked these slopes into behavioral priorities (e.g., Mason, Cooper, & Clarebrough, 2001).

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An alternative measure of value that can also be derived from demand functions is the consumer surplus or total quantity demanded over a range of cost (Varian, 1996), which is calculated as the area under the demand curve (Houston, 1997; Kirkden, 1999; Ng, 1990). This approach has, however, been criticized since it may overestimate the value of commodities with a high rate of consumption at low costs compared with resources that require small amounts of time for satisfactory expression (Dawkins, 1990). With this issue in mind, welfare scientists have conventionally used measures of elasticity derived from demand functions with which to assess the value of resources.

Operant approaches have been widely used to investigate the environmental preferences of captive animals (Kilgour, Foster, Temple, Matthews, & Bremner, 1991). Operant tasks are not only a simple method of imposing costs on access to resources, but they also allow automatic measurement of cost paid and consumption for deriving demand functions. These costs can take the form of leverpressing (Collier, Johnson, Cybulski, & McHale, 1990; Sherwin & Nicol, 1996), panel pressing (Matthews & Ladewig, 1994), or keypecking (Dawkins & Beardsley, 1986) to gain access to a resource. Operant tasks are not, however, limited to the tools of experimental psychology, and a number of other learned response tasks have been used to investigate demand. These include learning to overcome aversive or difficult obstacles, such as baths of water (Sherwin & Nicol, 1995), squeezing through narrow gaps (Cooper & Appleby, 1995, 1997), or pushing open weighted doors (Cooper & Mason, 1997a, 2000; Duncan & Kite, 1987; Petherick & Rutter, 1990). There is, however, debate regarding how best to derive measures of persistence or elasticity (Dawkins, 1990; Houston, 1997; Mason, Cooper, & Garner, 1997) from these approaches, since they might not conform to the constraints of consumer demand theory so that they do not meaningfully produce demand functions. With the use of operant approaches, a number of problems commonly arise when the value of alternative resources is compared; these include operant-reinforcer biases (Young, MacLeod, & Lawrence, 1994), failure to place a true cost on consumption (Larkin & McFarland, 1978), and failure to use an appropriate common currency. These have been reviewed elsewhere (Mason et al., 1998), so their effects will only be summarized in this paper.

First, the ability to overcome an operant task in order to gain access to a resource will depend on the reinforcing properties of the resource, the motivational state of the animal, and the ease of association between the operant task and the resource. For example, due to *biological preparedness* (Chance, 1988), any differences in the ease of association between the operant task and the resource may mask differences in their values. Dawkins and Beardsley (1986) found this effect when they were able to train chickens to peck a key for food, but not to peck for litter, although, in later studies, chickens have been trained to peck keys for litter (Gunnarsson et al., 2000). Nevertheless, careful consideration must be given

to the choice of operant task in order to minimize operant bias, and it may be necessary to use a number of different operant tasks before drawing firm conclusions about the relative value of alternative resources. In some studies, alternative approaches yield similar demand functions for the same reward (e.g., Sumpter, Temple, & Foster, 1999), whereas in others, the use of different operant tasks yields quite different demand functions for the same reward (e.g., Decker, Frimer, Hansen, & Jensen, 2000; Young et al., 1994). If demand functions can differ among operant tasks for the same reward, caution must be taken when deriving demand functions for different rewards. This is because their derivation is based on unitary changes in price across all resources, where unit price is a function of reward ratio, (e.g., fixed ratio with leverpressing), cost per action (e.g., lever weight), and amount of reward (Hursh, Raslear, Shurtleff, Bauman, & Simmons, 1988), and it is not clear in what way amount or reward can be fixed across different resources.

Careful consideration is also required when a measure of consumption is to be chosen, since demand functions are derived from the persistence of consumption in the face of price constraints. It is therefore important that the imposed cost truly places a cost on consumption and that this is equivalent for each resource under consideration. Ideally, this measure should be biologically meaningful (i.e., a reduction is likely to impinge on the functioning of the animal and ultimately its evolutionary fitness; Dawkins, 1990; Houston, 1997), and conventionally, time with the resource has been used as a measure of consumption. This measure has, however, been questioned, because unit time spent with a resource may not be equivalent for all resources and animals may find means of maintaining consumption without increasing cost (Mason et al., 1998). For example, when a cost is placed on access to the resource and not directly on consumption of the resource itself, once the cost has been paid, the animal may compensate for fewer visits by consuming more on each visit (Larkin & McFarland, 1978). As a result, price paid in terms of the number of times the animal overcomes the entry charge and amount consumed may not covary, so the animal's elasticity of demand may appear artificially high (Cooper & Mason, 1997a; Mason et al., 1997).

This effect has been found in laying hens (Cooper & Appleby, 1995, 1997); hens made fewer visits to enclosed nest sites when access was restricted by means of a narrow gap, but their time spent with the nest site was little affected by the cost on access. It has also been found in mice (Sherwin & Nicol, 1996); the increase in the number of leverpresses to enter compartments of different sizes had little effect on time spent in each compartment. Furthermore, direct observation of the test animals' behavior has shown that resource interaction is more intense once the animals overcome higher costs on access (Cooper & Mason, 2000), so the value of time spent with the resource may not be constant. As a consequence, measures based on time with the resource may underestimate resource consumption at higher access costs, and demand curves

derived from these measures may not be a true reflection of the value of different resources (Mason et al., 1998).

An alternative approach to demand curves is *reservation or maximum price*, which is the highest price individual animals are prepared to pay in order to gain access to resources (Figure 1). This measure is similar to *break point* in studies that have used progressive ratio schedules, in which the number of responses required increases up to the point when the animal ceases to respond (Hodos, 1961; Lawrence & Illius, 1989; Robinson, Foster, Temple, & Poling, 1995). Maximum price, however, has wider application than does break point, since it can be used with many forms of operant tasks (e.g., overcoming aversive barriers) that would not conventionally fit within the concept of unit cost (Hursh et al., 1988). Furthermore, maximum price paid or entry fee also avoids the methodological problems associated with the finding of common currencies from which to derive elasticity curves. Demand curves are not suitable for assessing the value of discrete, nondivisible resources, such as nest boxes or social contact, and in human economics, the price paid by each consumer for such resources (e.g., houses) is thought to be a more appropriate measure of the value of such goods (Varian, 1996). Finally, demand curves are good for measuring the price the market will bear, but are not so good for assessing customer satisfaction or the welfare benefits of the resource. Again, measures based on price paid rather than defense of consumption may be more appropriate when the benefits of resources to animals are considered (Houston, 1997; Kirkden, 1999).

Having discussed the problems of the use of demand curves to measure behavioral priorities and having put forward maximum price paid as an alternative means of maintaining the experimental elegance of operant techniques while providing a valid measure of value, the rest

of this paper reviews the use of this approach in a single species (the American Mink, *Mustela vison*). We present data from a series of papers on mink research.

### Behavioral Priorities of the Mink

The American mink is a semiaquatic carnivore. In the wild, mink occupy territories of several square miles, where they hunt, kill, consume, and cache prey, and they may occupy several nest sites (Dunstone, 1993). Mink are behaviorally and physiologically adapted for periods of fasting when prey is scarce and food caches have been exhausted (Dunstone & Birks, 1987; Dunstone & O'Connor, 1979). Territories are usually found at the edge of bodies of water such as rivers, lakes, and the sea, and although there is little overlap of territories of the same sex, male and female territories can overlap.

Mink are commercially farmed for their fur. On farms, mink are housed in rows of wire cages. A typical cage would measure 300 mm wide  $\times$  450 mm high  $\times$  600 mm long with access to an enclosed nest box, food, and water (Danish Fur Breeders Association, 1985; Nimon & Broom, 1999). In the northern hemisphere, mink pups are born in May and weaned at about 5 to 7 weeks of age, as compared with 8 to 13 weeks of age in the wild. Most mink are slaughtered at 6 months of age, though a proportion of young will overwinter and join the breeding population. The mink is an opportune species for the investigation of behavioral needs, since mink farming is likely to be banned in the UK and is subject to review of its husbandry elsewhere in the EU. Although the market for mink may be static or declining in the west, the world market for mink is rising because mink has become a symbol of economic success in developing nations.

In these studies, mink were individually housed in test arenas constructed from commercial mink cages. Each

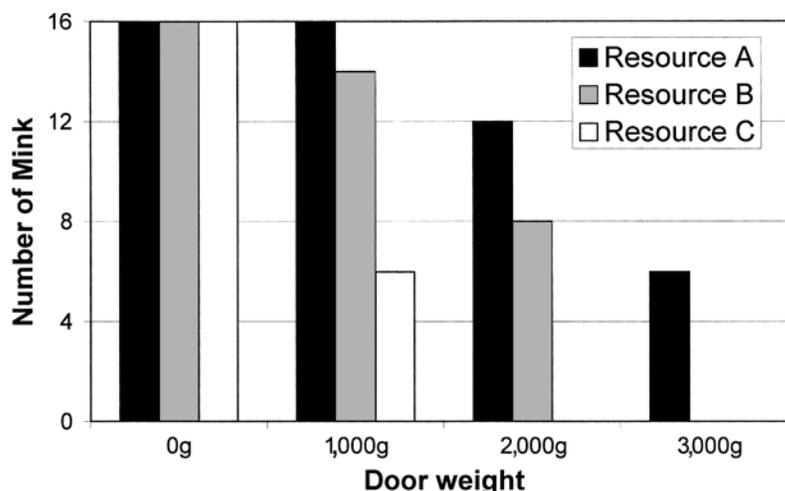


Figure 1. The number of mink prepared to pay each entry fee for three resources A, B, and C. Resource A would be more important than Resource B since more mink are prepared to pay a higher entry fee for this resource, with Resource C the least valued resource available. The reservation price (see Figure 4) for each resource is calculated as the average of the highest price paid by each mink.

arena consisted of a single home cage, containing a nest box, food, and water. This compartment replicated as far as possible the environment of the commercially housed mink. From this compartment, the mink had access to seven other compartments, each of which contained a different resource. Each compartment had a one-way entrance and a one-way exit. Each door had a reed switch and a magnet, so that opening and closing the door switched the reed on and off (Figure 2).

The cost on access to each of the seven resource compartments could be varied by attaching weighted blocks to the door. Eight test arenas were built so that the home-cage and seven resources could be represented in each of the eight cage positions. The mink were housed in the test arena for the duration of testing. This closed economy setup in which animals can only access resources within the test arena is an important criteria for the assessment of behavioral priorities (Mason et al., 1998). In an open economy, an animal can be tested for a short period of time and then returned to a holding cage between tests. In this situation, the test animal can learn not to work for access to a restricted resource since it can wait for free access to the resource or similar substitutes on return to its home environment.

A Paul Fray Arachnid random event recorder was used to record entry into and exit from each resource compartment via an Acorn RISCPC, although in principle, any hardware capable of detecting switch changes and of time stamping these events can be used in this approach. The program recorded each switch's change of state and the time since the last switch change. Each event was stored as a single line in a tab delineated text file that could then be processed using Borland Pascal for the PC. After processing, data was stored as the number of visits to each compartment and total time spent in each compartment.

In early trials, weights of up to 1,250 g were used (average female mink weight was about 1,000 g, and average male mink weight was about 1,800 g). Sixteen mink were tested (8 males and 8 females). In addition to free access to the home compartment, mink could pay entry fees to visit seven separate resources—a water bath with open water deep enough to swim in (bath), an alternative open nest box (hay), a raised platform that allowed for climbing (platform), an empty compartment (empty), a tunnel, cat toys, and a novel object that was replaced on each test day. Mink were tested for 7 days at costs of 0, 250, 500, 750, 1,000, and 1,250 g.

The increase in entry fee reduced the number of visits to all seven resources (Cooper & Mason, 1997a), suggesting that the increase in door weight imposed a cost on access to each resource (Figure 3). The average duration of visits increased so that, for several resources, including the bath, the alternative nest site, and the novel object, there was no change in the time spent with the resource as cost increased. Furthermore, video observations of a subset of the mink revealed that they spent a greater portion of their visits interacting with the resource (Cooper & Mason, 2000) as entry fee increased, which may be related to a higher motivational state associated with overcoming higher costs on access. Consequently, time in the resource compartment as measured by automatic means, does not give a true reflection of time spent consuming the resource. As a result, even with those resources such as toys or platform that showed a decline in the time spent with them in the resource compartments, the mink may have conserved consumption by more intense resource interaction during these visits. The benefits of operant technology for automatic data collection therefore appear to be lost when the operant cost is not placed directly on the consumption of the resource.

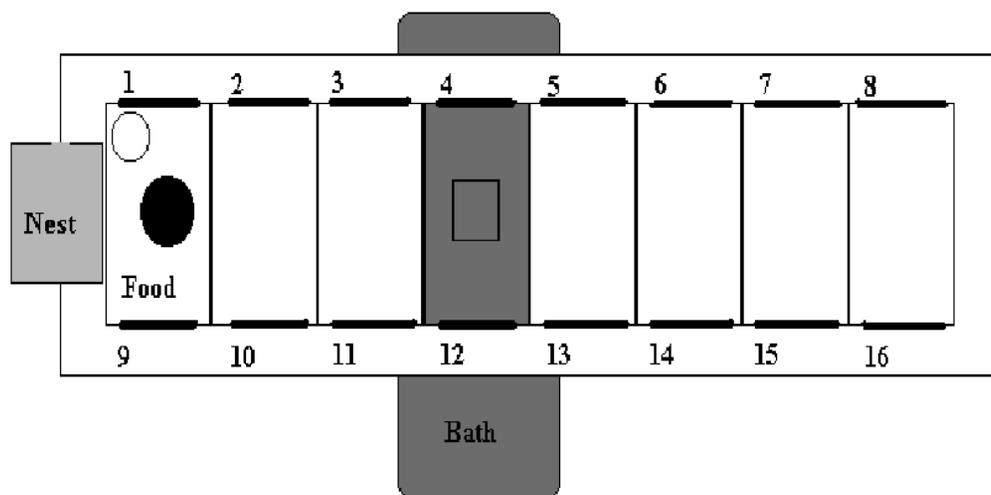


Figure 2. The test arena for the first cohort of 16 mink showing a home compartment with nest, food, and water, and a bath compartment with access to a water-filled bath below the arena. Also shown is the order of the 16 door switches that allows compartment visits to be recorded. Doors 1–8 are one-way entrances and doors 9–16 are one-way exits, so, for example, a mink would leave the home compartment via exit door 9 and enter the bath compartment via entrance door 4.

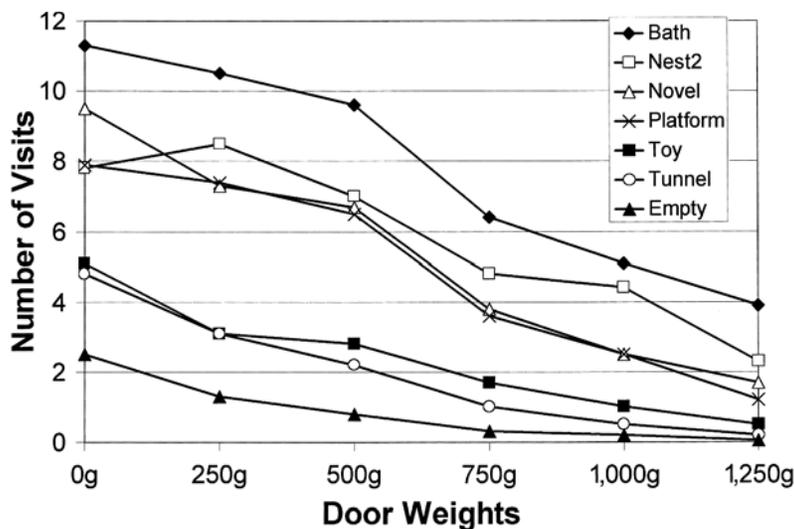


Figure 3. The effect of doorweight on the number of visits to each resource compartment. All seven resources showed a decline in number of visits with increased cost on access.

One solution to this problem is to limit the quantity of resources available per cost paid—for example, by providing a limited amount of food for each visit, or limiting visit time. Matthews and Ladewig (1994) used this approach when they investigated the behavioral needs of pigs, which had been trained to panel press for access to food, for a companion and for an empty compartment. They found that when visit time was restricted, number of visits and consequently time with resource dropped at a faster rate for companionship than for food. This approach has, however, been questioned by Mason et al. (1998), since the limiting of the length of bouts of resource interaction might differentially effect different resources. This is because consumption of certain resources (e.g., food) in small quantities might be more valuable than small quantities of others (e.g., access to bedding or access to a companion), since the time period or quantity of resource is inadequate to allow for full expression of the behavior. Studies of demand for dust-bathing material in laying hens (Matthews, Walker, Foster, & Temple, 1998) have found no effect of duration of fixed visits to the resource on demand function, though only a small range of visit lengths were used in this study. In contrast, in our own work with mink (Cooper & Mason, 1997b), when we restricted the time available to exploit all resources from 24 to 2 h per day, the resources with the highest consumption with free time (e.g., an alternative nest box to sleep in) showed the highest income elasticity. Furthermore, this approach does not solve the problem of more intense interaction with higher costs and higher motivational states on access (Larkin & McFarland 1978), which would mean time spent with the resource could still underestimate its value.

We therefore adopted the approach of maximum price paid, since this has the benefit of using operant costs and

automatic detection of resource visits; we abandoned the use of elasticity curves because of the inherent difficulties with common currencies. With costs on access of up to 1,250 g, number of visits to each resource declined, but most mink still managed to overcome the 1,250-g limit for a number of resources, so that it was not possible to discriminate between price paid for the bath, novelty, platform, or alternative nest site. In addition, as the rate of decline in number of visits was similar across all the resources (Figure 3), there appeared to be a relationship between number of visits with free access and number of visits at higher costs of access. If maximum price paid turned out to be a function of intensity of interaction at low costs, this would undermine the use of the measure to assess the value of resources.

A second experiment was therefore carried out with another 16 adult mink. They were tested in the same test arenas, but at higher weights (up to 3,000 g) and a new combination of resources, which were bath, novel object, toys, and cylinder from the original resources. In addition, we provided the mink with two new resource compartments, one with access to a water bowl in a bath and one with a social compartment where the mink could see their neighbors, but not physically interact with them. Finally, food was removed from the home compartment and was placed in its own resource compartment. Since food was not provided elsewhere in the test arena and is expected to be an important resource, we believed the price paid to enter the food compartment would act as a yardstick with which to compare the maximum price paid for other resources.

In the second cohort of mink, the increasing cost again reduced the number of visits, with many mink failing to overcome the high costs for particular resources (Cooper & Mason 1999, Mason et al., 2001). As a consequence,

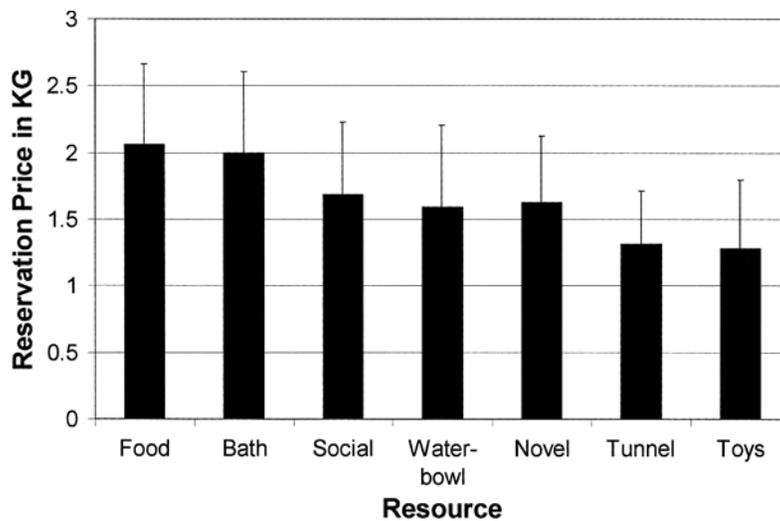


Figure 4. The reservation price paid by mink for access to the seven resources available to the second cohort of mink (mean maximum price  $\pm$  SE). Tukey's post ANOVA *t* test showed that mink overcame the highest costs for food and bath and the lowest costs for toys and tunnels with social arena, waterbowl, and novel object occupying intermediate positions.

the mink were unable to compensate for fewer visits with longer durations, and time spent with all resources declined. Nevertheless, for the reasons discussed above, demand functions derived from such data would still be open to doubt (Mason et al., 1998). At the higher entry fees, it was possible to differentiate between resources, with three levels of importance being apparent (Figure 4). Mink worked least hard for the toys and tunnels (mean maximum price of  $1,281 \pm 515$  g and  $1,312 \pm 403$  g, respectively). Mink worked harder for the bowl in the waterbowl ( $1,594 \pm 611$  g), the novel object ( $1,625 \pm 500$  g) and social areas ( $1,687 \pm 544$  g), and worked hardest for the bath ( $2,000 \pm 605$  g) and the food ( $2,062 \pm 602$  g). The highest price of all was paid by the strongest mink for food, but there was no statistical difference between price paid for bath and price paid for food (Mason et al., 2001). In this study, although there was individual variation in the minks' ability to open doors, there was no evidence of individual variation in ranking of resources and no relationship between the consumption of the resources with free access and maximum price paid for access.

### Discussion and Conclusion

Results suggest that mink place the highest value on food and bath. If additional resources were to be provided with the aim of improving the minks quality of life, a bath in which the mink could swim would be a good start. The results also suggest that mink do not value all resources equally and that the addition of objects such as toys or tunnels may have little effect on farmed mink's quality of life. These findings are supported by independent measures of welfare such as stress physiology (Mason et al., 2001). The prevention of access to resources by locking the entry doors resulted in increased stereotypy

in mink locked out of food and bath and increased corticosteroid production as assayed by urinary corticosteroids (Mason, Clarebrough, & Cooper, 1999).

In addition, these results point to maximum price paid as a solution to the problems associated with using demand functions to measure behavioral priorities, which is simple to use in practice and conforms to the constraints of economic theories. Price elasticity is conventionally calculated as the slope of the line of best fit when log consumption is plotted against log price with a fixed income (Houston, 1997; Matthews & Ladewig, 1994). If this measure was used to compare the value or utility of different resources, several assumptions have to be made. First, it is assumed that the measures of consumption are equivalent across all resources under consideration. The argument that this assumption is not safe has already been made in this paper. Furthermore, it is assumed that the rise in entry fee (unit increase in price) increases in a predictable manner. This may be possible with certain operant tasks, such as leverpressing, in which an FR16 may be four times as costly as an FR4, but is less safe with other tasks such as squeezing through narrow gaps or pushing weighted doors. Maximum price paid is not subject to such mathematical restrictions and allows for the practical measurement of value, including the use of automatic recording of the animal's location and the use of costs on access, which are generally simpler to impose than are direct costs on consumption.

These experiments concentrate on a single form of cost—namely, overcoming a weighted entry door. Consequently, these studies have not directly addressed the question of operant bias and the ease of association between performing the task and the reinforcer. Failure to overcome heavier door weight for certain resources may,

potentially, mean that there is an inappropriate combination of operant task and consequences rather than lower value to the resource. Observations of the mink as they habituated to the test arena suggest that this is unlikely to be a major problem with opening doors, since at low costs, mink readily opened doors to all resources and appeared to rapidly learn the locations of each resource compartment. Nevertheless, the possibility of operant bias still exists, and it would be useful to test the robustness of the minks' behavioral priorities with different operant tasks, such as leverpressing and chain pulling (Decker et al., 2000). In addition, ongoing work at Oxford is investigating other aspects of ease of association, such as the importance of visual cues, by comparing work for resources when they are visible at the point of access against work for resources that are out of sight.

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