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Animal Welfare 2004, 13: S115-120
ISSN 0962-7286

Mechanisms of decision-making and the interpretation of choice tests

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Abstract

Choice tests are commonly used to measure animals' preferences, and the results of such tests are used to make recommendations regarding animal husbandry. An implicit assumption underlying the majority of choice tests is that the preferences obtained are independent of the set of options available in the test. This follows from two assumptions about the mechanisms of choice: first, that animals use absolute evaluation mechanisms to assign value to options, and second, that the probability of choosing an option is proportional to the ratio between the value of that option and the sum of the values of the other options available. However, if either of these assumptions is incorrect then preferences can differ depending on the composition of the choice set. In support of this concern, evidence from foraging animals shows that preferences can change when a third, less preferred option is added to a binary choice. These findings have implications for the design and interpretation of choice tests.

Keywords: *animal welfare, choice test, context effect, foraging decision, Luce's choice axiom, preference*

Introduction

The results from behavioural choice tests have been widely used in animal welfare research as the basis for making recommendations regarding the husbandry of captive animals (see reviews in Forbes *et al* 1997). Here I re-examine the link between the preferences expressed by animals in choice tests and the conditions likely to promote good welfare, in the light of recent evidence that animal preferences may be dependent on the precise context in which a preference is measured.

The link between the resources preferred by animals in choice tests and improvements in welfare is not straightforward. A range of different behavioural measures of preference can be taken from a subject in a simple choice test, and an animal is generally deemed as preferring an option if it spends more time with it, chooses it more often, or has a shorter latency to approach it. The usual assumption in the welfare literature is that the rank and magnitude of these behavioural preference measures are likely to reflect the animal's underlying motivational priorities in the applied system of concern. Thus, the stronger the behavioural preference for an option, the stronger the animal's internal motivation to obtain this option. The establishment of motivational priorities has been a central aim of welfare research because it has been argued that suffering occurs when an animal is prevented from performing an activity or achieving a state that it is highly motivated to perform or achieve (Dawkins 1983, 1990). Hence, by giving animals the environments that they themselves have chosen we should be reducing suffering and consequently improving welfare. There have been two broad categories of criticisms of the use of choice tests in animal welfare research.

1. Fulfilling short-term motivational priorities may not produce long-term welfare

The justification for a link between giving an animal what it wants and improved welfare follows from the assumption that animals should have evolved to be motivated to avoid environments that are detrimental to their fitness. However, this may no longer be true in captive environments because choices that would have resulted in adaptive behaviour in the wild may no longer do so in captivity. Additionally, in the case of domesticated animals, it is possible that artificial selection has eroded animals' abilities to make adaptive choices. It is possible to sidestep both of these objections by arguing that even if the long-term consequences of a particular choice are not adaptive, as long as the physical health of the animal is not severely compromised its welfare may still be maximised by giving it what it wants (eg Nicol 1997).

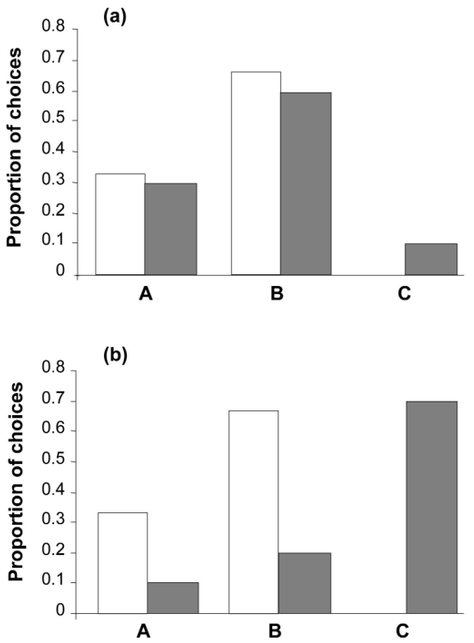
2. Motivational priorities are not fixed

The most common criticism of choice tests concerns their relevance to situations outside the context in which the choice experiment was performed (Mason *et al* 1997). Motivational priorities established in one context may differ in another because:

(1) Animals of different species, breeds or sexes may have different preferences.

(2) Preferences may change with an animal's age or reproductive state, with the time of year or day (eg Cooper & Appleby 1995), or as a result of previous experience (eg Grandin *et al* 1994).

Figure 1



Two illustrations of where the addition of a third option, C, to a binary choice of A and B has no effect on the relative preference for B over A. Preferences from binary comparisons are shown by the empty bars, whereas preferences from the trinary comparisons are shown by the filled bars. Panel A shows a case where C is the least preferred option and takes little preference share from A and B. Panel B shows a case where C is the most preferred option and takes the majority share of preference. In both cases the constant ratio rule is fulfilled because although the absolute preference for A and B declines, the relative preference for B over A is maintained at 2:1. The effects shown here represent the usual assumption underlying choice tests: that preferences will be independent of the choice context.

(3) Animals may change their preferences according to the time or energy budgets that they have available to them (Inglis & Ferguson 1986; Houston & McNamara 1989).

(4) The cost associated with acquiring resources can theoretically affect preferences if resources differ in their price elasticity.

(5) Preferences may be affected by the length of access to a resource permitted in an experiment (eg Matthews & Ladewig 1994).

(6) The availability of cues from resources can affect preference (eg Warburton & Mason 2003).

(7) The number and type of resources available in the experiment can affect preference (see below).

In order to ensure the external validity of choice experiments, it is therefore important to use subjects that are in a state and environment as similar as possible to those of the captive animals whose welfare the aim is to improve (Mason *et al* 1997). The effects listed in points 1–6 above have already received some attention in the welfare literature; however, although the potential effects of the number and type of options in the choice set (point 7) have been acknowledged (eg Mason *et al* 1997; Nicol 1997), it is usually assumed that the preferences obtained from choice tests are independent of the composition of the choice set.

Effects of changing the choice set

In order to illustrate the potential effects of the composition of the choice set, I shall start by considering a subject faced with a binary choice between options A and B. These options can be thought of as any resources for which we are seeking to obtain preference measures. I shall assume that in the binary choice situation of A versus B, the subject has a partial preference for B over A, allocating two thirds of its preference to B. I will describe three possible effects on preference of adding a third option, C, to the choice set. Note that the absolute preference for an option is calculated as the ratio of the number of choices made to that option to the total number of choices made. For example, the absolute preference for A in a binary context is A / (A + B), and in a trinary context A / (A + B + C). In contrast, the relative preference for one option over another is calculated as the ratio of the number of choices made to one option to the number of choices made to both options. For example, the relative preference for A over B is A / (A + B) in both binary and trinary contexts.

1. Option C has no effect on the relative preference for A and B

Although this issue is rarely explicitly discussed in the welfare literature, the implicit assumption made in most studies of choice is that the relative preference for B over A will be unchanged by the addition of one or more options to the choice set. Thus, although the absolute preferences for options A and B are likely to be decreased by the addition of option C (assuming that option C takes some of the share of preference), the ratio of preference for B over A will be maintained at 2:1 (Figures 1a and 1b). This is known as the constant ratio rule, and it follows from making two assumptions about the mechanisms underlying choice: first, that subjects assign absolute values to options that are independent of the composition of the choice set, and second, that the mechanism that translates the value of options into choice behaviour follows Luce's choice axiom, meaning that the probability of choosing an option is proportional to the ratio between the value of that option and the sum of the values of the other options available (Luce 1959). These two assumptions are fundamental to most existing biological and economic models of animal choice (eg McNamara & Houston 1987).

2. Option C causes an increase in the relative preference for A or B

In this case C takes its share of preference disproportionately from either A or B, resulting in a change in the relative preference for B over A (Figures 2a and 2b). In extreme cases relative preference could shift such that the ranking of A and B is reversed in the presence of the third option. Such violations of the constant ratio rule can occur when either of the above two assumptions regarding the mechanisms of choice

https://doi.org/10.1017/S0962728600014457 Published online by Cambridge University Press

is relaxed. Thus, a violation of the constant ratio rule implies either that animals do not assign absolute values to options, or that choices are not allocated in accordance with Luce's choice axiom.

3. Option C causes an increase in the absolute preference for A or B

In this case, C causes the absolute share of preference taken by either A or B to increase relative to the absolute level of preference the option has in the binary choice set (Figure 3). This constitutes a violation of the constant ratio rule but also a violation of regularity. Regularity is a fundamental principal of rational choice whereby the addition of an option to a choice set should never lead to an increase in the absolute level of preference for one of the original options. If regularity is violated this implies that animals do not assign absolute values to options, but instead assign values using a comparative mechanism that takes account of the other options available in the choice set (Tversky & Simonson 1993).

Circumstances in which violations of the constant ratio rule are expected

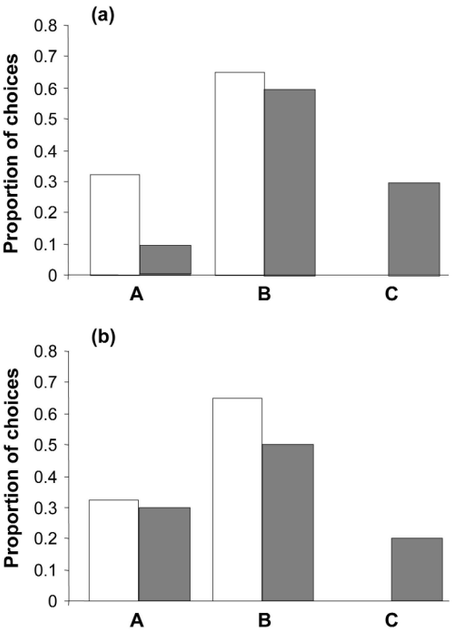
Above, I have identified two potential causes of violations of the constant ratio rule: first, that subjects may not assign absolute values to options, and second, that animals may not translate values into preferences in accordance with Luce's choice axiom. I shall now attempt to identify some of the circumstances in which these two problems are likely to be encountered.

Circumstances in which assignment of value might be context-dependent

A straightforward case in which the value assigned to an option is not an absolute property of that option, but is determined by the other options in the choice set, is when the option added to the choice set either substitutes for one of the existing options, and thus reduces its value by competing with it, or complements one of the existing options, and thus enhances its value (Debreu 1960; Varian 1996). For example, captive mink appear to assign a much higher value to a water pool to play in, than to toys, in an experiment in which seven different resources were available (Mason *et al* 2001). However, it is possible that in the absence of the water pool, toys would have been valued more highly because they might provide an alternative outlet for play behaviours and therefore might be used more extensively when the preferred pool is not available. Thus, a water pool and toys could be resources that substitute for each other such that each has a higher value to the animal in the absence of the other. In the same study, a raised platform was valued more highly than toys by the mink. However, the mink tended to use this platform to dry out after swimming in the pool, and it is therefore possible that the pool and platform were complements that would individually have lower values to the mink (G Mason 2003, personal communication).

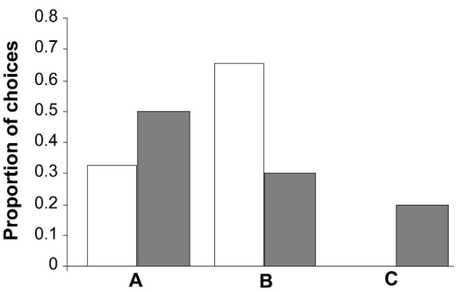
A more complex scenario, in which the assignment of value may not be absolute, occurs when the options in the choice set are all substitutes for one another that vary in two or more dimensions of interest to the subject. For example, in the marketing literature, alternative products that consumers are faced with generally vary in both price and quality, and similarly, different bedding types being compared in an animal choice test might vary in, say, comfort, dustiness and

Figure 2



Two illustrations of where the addition of option C to a binary choice of A and B causes a change in the relative preference for A and B. Binary and trinary comparison data are indicated as in Figure 1. In panel A the addition of C causes an increase in the relative preference for B. In panel B the addition of C causes an increase in the relative preference for A. Such results imply either that animals do not assign absolute values to options, or that choices are not allocated in accordance with Luce's choice axiom.

Figure 3



An illustration of where the addition of option C to a binary choice of A and B causes an increase in both the relative and the absolute preference for option A, and hence a violation of regularity. Binary and trinary comparison data are indicated as in Figure 1. Note that there is also a reversal in the direction of preference for A and B between the binary and trinary comparisons. Such results imply that animals do not assign absolute values to the options, but that the value of an option is computed relative to the other options available in the choice set.

https://doi.org/10.1017/S0962728600014457 Published online by Cambridge University Press

Table 1 Comparison of absolute and comparative evaluation mechanisms. Each cell contains the absolute value of the option on the dimension followed by the relative rank of the option on that dimension in brackets. See text for details.

A: Binary comparison of options A and B

	Option A	Option B
Dimension 1	40 (1)	20 (2)
Dimension 2	20 (2)	40 (1)
Total	60 (3)	60 (3)

B: Trinary comparison of options A, B and C

	Option A	Option B	Option C
Dimension 1	40 (1)	20 (3)	30 (2)
Dimension 2	20 (2)	40 (1)	10 (3)
Total	60 (3)	60 (4)	40 (5)

edibility (eg Mills *et al* 1997). In order to make a choice amongst options varying in multiple dimensions the subject requires a mechanism to combine the information about the different dimensions. An absolute evaluation mechanism would assign an absolute value to each option by integrating the absolute value of each dimension into a single overall value. For example, in the optimal foraging literature, net rate of energy intake is the currency used to integrate the energy obtained from a particular prey type and the time taken to handle and consume it. Alternatively, a comparative evaluation mechanism might rank the available options on each dimension separately and use the sum of these ranks to arrive at an overall ranking of the options. For example, Table 1A compares how an absolute and a comparative evaluation mechanism might value two options, A and B, which differ along two dimensions. An absolute mechanism might compute a value for each option by summing the values it takes on each of the two dimensions. A and B both score a total of 60 (20 + 40) using this mechanism, and A is therefore judged equal in value to B. In contrast, a comparative mechanism might first rank the options along each dimension, and then sum the ranks from the two dimensions to arrive at a total value for each option. A and B both have a total rank of 3 (2 + 1), thus again A is equal in value to B. Comparative mechanisms such as this might have been favoured by natural selection because they usually produce similar results to absolute mechanisms, but are computationally more efficient due to the greater ease of making comparisons along single dimensions and the use of relative ranks rather than absolute values (Tversky 1969; Shafir 1994; Gigerenzer *et al* 1999).

The problem with comparative evaluation mechanisms is that unlike absolute mechanisms they can be sensitive to the composition of the choice set. For example, Table 1B shows the same two options A and B from Table 1A with the addition of a third option C. The absolute values for options A and B are unchanged from Table 1A, with A being equal in value to B. However, because the comparative values rely on ranks, and because option C ranks between options A and B on dimension 1, the presence of option C in the choice set changes the comparative values of A and B such that now A has a higher total value (ie lower sum of ranks) than B. This effect is known as the asymmetrically dominated effect (Huber *et al* 1982), because it occurs when the third option C (know as an asymmetrically dominated decoy) occupies a specific position relative to options A and B, such that it lies between A and B on dimension 1, but is worse than both A and B on dimension 2.

Circumstances in which Luce's choice axiom may not apply

Violations of regularity (as in Figure 3) can occur only if subjects use comparative as opposed to absolute mechanisms to evaluate options; however, violations of the constant ratio rule without violations of regularity (as in Figure 2) can also occur if subjects use mechanisms other than the choice axiom to allocate choices amongst options. Although Luce's choice axiom is commonly assumed in models of choice to account for partial preferences, there are many other mechanisms that could explain why animals do not allocate all of their choices to the most preferred option. For example, in an alternative scenario, a subject may allocate some fixed proportion of its choices to the option with the highest value but allocate the remaining proportion of its choices between the available options at random. This pattern of choice is particularly likely in experimental designs where the spatial arrangement of the options is randomised on each trial in order to avoid the possibility of animals with spatial biases producing spurious preference data. On a fixed proportion of trials the animal may choose the option with the highest value independent of its location, but on the remaining proportion of trials it may display a side bias and always choose, say, the left-hand option. Since the option presented on the left is randomised between trials, such a side bias will result in the animal allocating its choices randomly amongst the available options on the trials in which it is side-biased. A counter intuitive outcome of such a choice mechanism is that a preference present in a binary context will be enhanced by the addition of one or more lower value options to the choice set. This effect (referred to as 'random dilution' by Bateson 2002) occurs because the additional options serve to absorb some of the random choices, and thus dilute the effect of the random choices on the observed preference for the highest value option.

Context-dependent choice in animals

Until recently most of the experimental evidence for effects of the composition of choice sets on preference has come from the human psychology and marketing literature (Huber *et al* 1982; Wedell 1991). For example, Doyle *et al* (1999) demonstrated that they could shift sales of baked beans in favour of a high quality, high price brand by introducing an asymmetrically dominated decoy that consisted of small cans of the same high quality brand that were proportionately more expensive than the larger cans. Animal studies investigating the effects of the choice set on preference all come from the foraging literature, and compare the

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Table 2 Summary of recent animal studies that have compared preferences obtained from binary and trinary choice sets.

Species	Options compared	Effect of changing the choice set*	Possible explanation(s)	Reference
Honeybee (*Apis mellifera*)	Artificial flowers differing in corolla length and volume of nectar contained.	Change in relative preference (2).	Comparative evaluation.	(Shafir *et al* 2002)
European starling (*Sturnus vulgaris*)	Options differing in the variance in number of food pellets.	Change in relative preference (2).	Comparative evaluation or random dilution.	(Bateson 2002)
Gray jay (*Perisoreus canadensis*)	Feeding stations differing in the length of a wire tunnel and the number of raisins contained.	Change in absolute preference (3).	Comparative evaluation.	(Shafir *et al* 2002)
Rufous hummingbird (*Selasphorus rufus*)	Artificial flowers differing in variance in nectar volume.	Change in absolute preference and preference reversal (3).	Comparative evaluation.	(Hurly & Oseen 1999)
	Artificial flowers differing in volume and concentration of nectar contained.	Change in relative preference (2).	Comparative evaluation or random dilution.	(Bateson *et al* 2002)
	Artificial flowers differing in volume and concentration of nectar contained.	Change in relative preference (2).	Comparative evaluation.	(Bateson *et al* 2003)
	Artificial flowers differing in variance in nectar volume.	Change in absolute preference and preference reversal (3).	Comparative evaluation.	(Hurly 2003)

* Numbers in brackets refer to the relevant figure in this paper.

preferences obtained from binary choices with those from trinary choices, usually when a third lower value option is added to the choice set. Table 2 summarises the results of several studies, all of which show increases either in relative preference (ie a violation of the constant ratio rule) or absolute preference (ie a violation of regularity) when a third option is added to the choice set.

Conclusions and animal welfare implications

I have presented data showing that both the magnitude and the direction of animals' foraging choices can be affected by adding a third option to a binary choice. These data have important implications for the interpretation and use of the preference data derived from choice tests, because the preferences displayed by animals in one choice context (eg a binary choice test) may not generalise to other choice contexts (eg trinary tests). In welfare research, where the outcomes of choice tests are used to make recommendations about animal husbandry, it is therefore important to establish that preferences are stable in different choice contexts if sound recommendations are to be made. The examples presented in this paper suggest three specific situations in which the number and range of options available in a choice set might affect choice:

(1) In experiments where a range of very different resources are being simultaneously compared it is vital to establish whether these resources could substitute for or complement one another. Such information can be gleaned by examining whether there are patterns in the way that particular resources are utilised by an animal. For example, if mink always go to the raised platform directly after swimming then it is reasonable to hypothesise that these two resources are complements. If substitutes or complements are suspected then it is vital to test the value of resources in different choice sets.

(2) In experiments where a range of close substitutes are compared that potentially differ in two or more dimensions of importance to the subject, it is important to establish whether the animal combines these dimensions using an absolute or comparative evaluation mechanism. Such information can be gleaned by establishing whether violations of regularity occur when the choice set is altered.

(3) In experiments where positional biases are a problem, and the location of options is randomised in order to prevent spurious preferences being measured, it is important to realise that Luce's choice axiom may not hold, and thus preferences may be affected by the number of options in the choice set.

Acknowledgements

I am very grateful to Georgia Mason for discussing the ideas presented in this paper with me and for greatly improving the manuscript. I thank the Royal Society and the Natural Environment Research Council for financial support.

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