Behavioural Processes

Four-alternative choice violates the constant-ratio rule

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ABSTRACT

Six pigeons responded on a four-key concurrent variable-interval schedule in which a 27:9:3:1 distribution of reinforcers between the keys changed every 10 reinforcers. Their behaviour quickly came under the control of this changing four-way reinforcer ratio. However, preference between a pair of keys depended not only on the relative reinforcer rates on those keys, but also on the absolute levels of those rates. This contradicts the constant-ratio rule that underpins the matching approach to choice, but is predicted by a contingency-discriminability model that assumes that organisms may occasionally misattribute reinforcers to a response that did not produce them. Reinforcers produced strong preference pulses, or transient increases in responding on the just-reinforced key. Despite accurate tracking of the reinforcer ratio, reinforcers obtained late in components and from leaner keys still produced strong pulses, suggesting both extended and local control of behaviour. Patterns of switching between keys were graded and similarly controlled by the reinforcer rates on each key. Whether considered in terms of switching, local preference pulses, or extended preference, behaviour was controlled by a rapidly changing four-way reinforcer ratio in a graduated, continuous manner that is unlikely to be explained by a simple heuristic such as fix-and-sample.

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1. Introduction

Since Findley (1958), the vast majority of the several hundred papers on concurrent variable-interval (VI) schedules published in the behavioural literature have investigated choice between two alternatives. Such behaviour is usually well described by the generalized matching law (Baum, 1974):

$$\log \frac{B_1}{B_2} = a \, \log \frac{R_1}{R_2} + \log c, \tag{1}$$

where B measures responses emitted or time spent, and R measures reinforcers obtained, at the alternatives denoted by the subscripts. Eq. (1) plots as a straight line. Its slope a is called sensitivity to reinforcement (Lobb and Davison, 1975), and describes the extent to which changes in the reinforcer ratio produce changes in the response ratio. Values between 0.8 and 1.0, or slight undermatching, are typical (see reviews by, e.g., Baum, 1979; Davison and McCarthy, 1988; Taylor and Davison, 1983). The intercept log c is called bias, and measures any systematic preference between the alternatives that is not accounted for by variation in the reinforcer ratio.

A general description of choice should, however, encompass choice between more than two alternatives. These procedures are much rarer in the literature, but most of the available data are also consistent with generalized matching. Davison and Hunter (1976) reported pairwise generalized matching between any two of three alternatives arranged concurrently. Reanalyses by Davison and McCarthy (1988) also showed that Eq. (1) satisfactorily described data from Pliskoff and Brown (1976), who arranged a switching-key concurrent schedule with three alternatives, and from Miller and Loveland (1974), who arranged a five-key concurrent schedule. Graft et al. (1977) reported pairwise undermatching, with typical sensitivity values, for both individuals and a group of rats living in a complex maze with VI-scheduled food reinforcement available on five operanda. Jensen and Neuringer (2009) reported data from rats responding on a five-alternative (two levers and three keys) concurrent schedule that were well described by generalized matching.

These results are important to a general understanding of choice because they bear on the principle of indifference from irrelevant alternatives, or the constant-ratio rule (Luce, 1959). This rule states that choice between a pair of alternatives should be independent of the existence, or value, of other alternatives. Prelec (1984) showed that generalized matching was a necessary consequence of two variants of the rule, a full discussion of which goes beyond our purposes here (see Elliffe and Alsop, 1996; Elliffe et al., 2008). The constant-ratio rule thus both offers a simple benchmark against which principled theories of choice can be measured, and underpins the most widely used description of choice, generalized matching. It needs to be tested.

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Davison et al. (2007) reported data that were not consistent with the constant-ratio rule, or with a generalized-matching description of choice. Their interest was in speed of learning, or adaption to changing reinforcer ratios, in rats that were the offspring of either normally nourished mothers or of mothers that had been undernourished during pregnancy. To investigate this question, Davison et al. used a modified version of a procedure introduced by Belke and Heyman (1994), and later developed first by Davison and Baum (2000) and in a series of subsequent papers by Davison, Baum and various colleagues, all using pigeons as experimental subjects.

In this procedure, a session arranges a series of components, each lasting for a predetermined number of reinforcers, most often ten. Each component arranges a different reinforcer ratio on the concurrent alternatives. When a component begins, choice is usually close to indifference, but responding to each alternative adapts remarkably quickly to the new reinforcer ratio, and so differentiates very rapidly as successive reinforcers are obtained at the new reinforcer ratio. In generalized-matching terms, sensitivity to reinforcement approaches an asymptote of around 0.5 when about six to eight reinforcers have been obtained in a component (e.g., Davison and Baum, 2000, 2002; Landon et al., 2003).

Breier et al. (2005) used this procedure to demonstrate that sensitivity increased within a component to a higher asymptote in rats with normally nourished mothers than in the offspring of undernourished mothers. Davison et al. (2007) tried to extend this finding to a similar, rapidly changing, four-alternative concurrent VI VI VI VI schedule. Components lasted for 5, 10, or 20 reinforcers in different conditions. The four-way reinforcer ratio was always 27:9:3:1, but these reinforcer rates were allocated randomly to the four nose-poke alternatives afresh for each component. Again, response rates to the four alternatives rapidly differentiated within a component. Davison et al. found no differences attributable to maternal nutrition, but they also analysed their data in a different way. Their Fig. 4 plots, averaged across components, log response ratio as a function of log reinforcer ratio for pairs of alternatives arranging reinforcer ratios of 27:1, 27:3, and 27:9, and, separately, for ratios of 27:1, 9:1, and 3:1. Both plots departed systematically from the straight line predicted by generalized matching (Eq. (1)). Choice was more extreme when the ratio was 27:3 than when it was 9:1, although both ratios favour one alternative by 9:1. Similarly, a 27:9 ratio produced more extreme choice than did a 3:1 ratio. That is, choice changed when the reinforcer ratio on a pair of alternatives remained constant, but the overall reinforcer rate on those alternatives was varied (see also Alsop and Elliffe, 1988; Elliffe and Alsop, 1996). This is inconsistent with the constant-ratio rule, and with the assumption inherent in the matching approach that relative, rather than absolute, reinforcer rates control choice.

Davison et al. (2007) found that their data were very accurately described by an extension (to be described in detail later, when we report a similar analysis) of the contingency-discriminability model (Davison and Jenkins, 1985; Davison and Nevin, 1999), which explains changes in sensitivity to reinforcement in terms of the extent to which the animal discriminates the relationship between responding and reinforcement on two alternatives. If the animal misattributes reinforcers on one alternative to responses on the other, this contingency discriminability is low. In the limit, indifference results if attribution of reinforcers to alternatives is no more accurate than chance. If the animal never misattributes reinforcers, contingency discriminability is infinite and the model predicts strict matching. Unlike the generalized matching law, this model need not predict that, for example, a 27:3 reinforcer ratio is as easily discriminated as a 9:1 ratio – perhaps, reinforcer misattributions might be more likely if reinforcement is relatively infrequent, so that contingency discriminability is smaller for 9:1 than for 27:3. That is, the model neither depends on nor predicts the constant-ratio rule.

Because of the far-reaching implications of Davison et al.'s (2007) result for understanding choice, we replicated their experiment, but using pigeons rather than rats as subjects. It is important to establish the generality of their result across species, because there is some suggestion that the change from steady-state to rapidly changing procedures affects rats' and pigeons' behaviour differently. As noted above, pigeons' sensitivity to reinforcer rate in rapidly changing procedures (e.g., Davison and Baum, 2000; Landon et al., 2003) reaches an asymptote of around 0.5, substantially lower than typical steady-state sensitivity, but rats' sensitivity appears to approach strict matching after a similar number of reinforcers in a component (e.g., Aparicio and Baum, 2006; Aparicio et al., 2009). Also, Davison et al.'s focus on the effects of maternal nutrition meant that they did not continue experimental conditions for as many sessions as typical in previous research using rapidly changing concurrent schedules. We ran many more sessions, both to assess the unlikely possibility that Davison et al.'s result was transient, and would disappear with extended training, and to allow two further analyses.

The first of these offers a more local analysis of choice. Davison and Baum (2002) first analysed, in a rapidly changing concurrent schedule, choice as a function of time since reinforcement. They found clear and orderly *preference pulses*. Immediately following reinforcement, choice very strongly favours the just-reinforced alternative. With increasing time (or number of responses) since reinforcement, choice becomes progressively less extreme, and approaches indifference (Davison and Baum) or, if reinforcers are overall more likely on one alternative than the other, the overall reinforcer ratio (Landon et al., 2003). Pulses also occur in steady-state, as well as rapidly changing, concurrent schedules (Landon et al., 2002; see also Buckner et al., 1993; Menlove, 1975), and tend to be larger in both amplitude and duration following reinforcers obtained from a high-rate alternative than a low-rate alternative (Davison and Baum, 2002; Landon et al., 2002). Sequences of reinforcers obtained from the same alternative tend to produce pulses of similar shape, but that are also displaced in the direction of more extreme choice of that alternative (e.g., Krägeloh et al., 2005). We were interested to see whether similar preference pulses occur in a four-alternative, rapidly changing procedure, and so needed enough sessions of data to allow their detection.

We were also interested in examining patterns of switching between the four alternatives. An unpublished dissertation by Murrell (1995), conducted in our lab, arranged a series of steady-state, switching-key, concurrent VI VI VI schedules. As well as providing some evidence against the constant-ratio rule, Murrell noted a consistent pattern of switching. His pigeons almost always returned to the richest (i.e., that offering the highest reinforcer rate) of the three alternatives after responding on one of the leaner alternatives, and very seldom switched between the two leaner alternatives. This pattern may reflect fix-and-sample behaviour (Baum, 2002), in which animals fix on the richer alternative of a two-alternative concurrent schedule, but occasionally sample the leaner alternative. In a concurrent schedule with more than two alternatives, this view of behaviour appears to predict consistent switches back to the richest alternative after occasional samples of one of the leaner alternatives. We were interested to see whether a similar pattern of switching characterized a rapidly changing, four-alternative procedure, and whether any such pattern would change as responding differentiated as a component progressed.

2. Materials and methods

2.1. Subjects

Six experimentally naïve homing pigeons served as subjects. They were numbered 81 through 86, and were maintained at