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Quantifying transitions in response allocation with change point analysis in concurrent chains

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ABSTRACT

Research based on the matching law has demonstrated empirically that the physical and temporal properties of the events, the context in which they occur and the signals that mark them in space and time all contribute to response allocation. When the physical or temporal properties of different outcomes change in ways that affect their relative value, the ratio of responses to each outcome adjusts with time and exposure to the new contingency. Five pigeons pecked in concurrent-chain schedules with fixed-interval terminal links. Terminal-link schedules were changed each session. In most sessions, response allocation was initially indifferent to terminal-link schedules but shifted to favor the initial link associated with the shorter terminal link. As a first step to disambiguating response allocation in transition from stable response allocation, transition durations were interpolated from change points in cumulative response plots. The relation between transition duration and absolute log immediacy ratio was negative: the number of initial links until the shift occurred was longer when terminal-link schedules were relatively similar than when they were relatively different.

Quantifying transitions in response allocation with change point analysis.

1. Generalized matching and choice in transition

The generalized matching relation (Baum, 1974; Staddon, 1968) describes allocation of time or responses as a power function of the allocation of reinforcers among different outcomes. When expressed in logarithmic terms, the generalized matching relation is a linear function:

$$\log\left(\frac{B_1}{B_2}\right) = s\log\frac{R_1}{R_2} + \log b. \tag{1}$$

In Eq. (1), *Bs* are response rates, *Rs* are rates of reinforcement, and numeric subscripts indicate different available outcomes (e.g., different concurrently operating schedules of reinforcement). The s parameter is sensitivity to reinforcement rate. Log b is bias; a preference for one outcome over another (in this case, for outcome 1 if > 0 and for outcome 2 if < 0) that is independent of relative reinforcement. Various quantitative iterations of matching have provided accurate descriptions of steady-state response allocation between outcomes that differ in different dimensions of reinforcement including rate, delay and amount (Berg and Grace, 2004), and of response rates in simple schedules (Herrnstein, 1970). As an empirical framework, the generalized matching relation has been applied to individual and group choice in a variety of laboratory and naturalistic settings (see Poling et al., 2011 for review).

Does relative value control how quickly response allocation adapts? The established transformation (a power function) provides a utilitarian empirical description of stable response allocation, and can serve as a foundation for a theory of choice dynamics. Determining how long it takes for response allocation to adjust when relative reinforcement changes is an important next step in the development of such a theory.

Delay to reinforcement is a well-studied reinforcer dimension. Concurrent-chain schedules are often used in research examining sensitivity to delays so that opportunities to choose between outcomes that differ in delay to reinforcement are equated. In typical concurrent-chains procedures (Herrnstein, 1964), subjects respond to two concurrently-presented signaled options or ‘initial links’ that operate on variable interval (VI) schedules. Responding in initial links produces either of two mutually-exclusive outcomes or ‘terminal links’ that end with food after the terminal-link schedule has elapsed. In these studies, relative reinforcement is characterized by immediacy ratios, where immediacy is the reciprocal of delay. The schedule with the shorter delay to reinforcement is the richer schedule, and the immediacy ratio quantifies how much richer.

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Matching has been described as a tautology (Rachlin, 1971; Killeen, 1972): if response ratio is an operational definition of relative value, the relevant empirical question in concurrent chains is not whether *matching* occurs when relative immediacy is changed, but rather what quantitative transformation describes the functional relation between the initial-link response ratio and the terminal-link immediacy ratio. Dependently scheduled initial links (Stubbs and Pliskoff, 1969) control access to terminal links so relative immediacy can be manipulated as an independent variable. In concurrent-chain schedules with dependently scheduled terminal-link entry, generalized matching holds that log initial-link response ratio is a linear function of log terminal-link immediacy ratio:

$$\log\left(\frac{B_1}{B_2}\right) = s\log\frac{1/D_1}{1/D_2} + \log b. \quad (2)$$

In Eq. (2), *Ds* are delays from terminal-link onset to food delivery and other variables are as in Eq. (1). Eq. (2) is an accurate, robust quantitative description of steady-state response allocation in concurrent chains, typically accounting for more than 90% of the variance (Grace, 1994). When terminal links are fixed time or fixed interval (FI) schedules, overmatching, i.e., $s > 1$ is the usual result (Omino and Ito, 1993).

Applying Eq. (2) to the same immediacy ratios presented in different contexts can delineate factors that circumscribe the generality of specific estimates of sensitivity to immediacy. Most empirical research investigating sensitivity to immediacy has involved steady-state concurrent-chain schedules in which the same schedules operate for many sessions (Grace and Hucks, 2013). However, contingencies that control delays to reinforcement in natural environments are rarely permanent. The rate at which relative immediacy changes may impact sensitivity to relative immediacy. For these reasons, characterizing and studying choice in transition and the interaction between choice dynamics and sensitivity to relative immediacy are vital empirical components in the development of contemporary theories of behavior.

1.1. Acquisition of sensitivity to relative immediacy

Kyonka and Grace (2007, 2010) studied choice in transition using concurrent chain schedules in which the log terminal-link immediacy ratio was changed pseudorandomly each session. In maximal-variation conditions, terminal links were FI schedules that were changed pseudorandomly each session. Within a session, the FI produced by the left initial link and the FI produced by the right terminal link always summed to 30 s (Kyonka and Grace, 2007) or either 15 s or 45 s, depending on condition (Kyonka and Grace, 2010). In this way, the overall rate of reinforcement in a session was always the same within a condition. The shorter FI terminal link was assigned to the left or right according to a 31-step pseudorandom binary sequence (Hunter and Davison, 1985). Immediacy ratios from previous sessions did not predict upcoming log immediacy ratio or location of the shorter FI. In order for response allocation to be sensitive to relative immediacy, pigeons had to learn terminal-link FIs and adjust initial-link responding accordingly within a session.

Kyonka and Grace (2007) showed that, after extensive training in the dynamic concurrent-chains procedure, pigeons' response allocation adjusted. At the beginning of sessions, during the first 12 (of 72) initial links, response allocation was typically indifferent, with roughly equal pecks to left and right initial links, and insensitive to immediacy ratios from current and previous sessions. Response allocation did not immediately adjust to new immediacy ratios, but there was no evidence of carryover control by previous immediacy ratios, either. By the ends of sessions, response allocation reliably favored the initial link that produced the shorter terminal link.

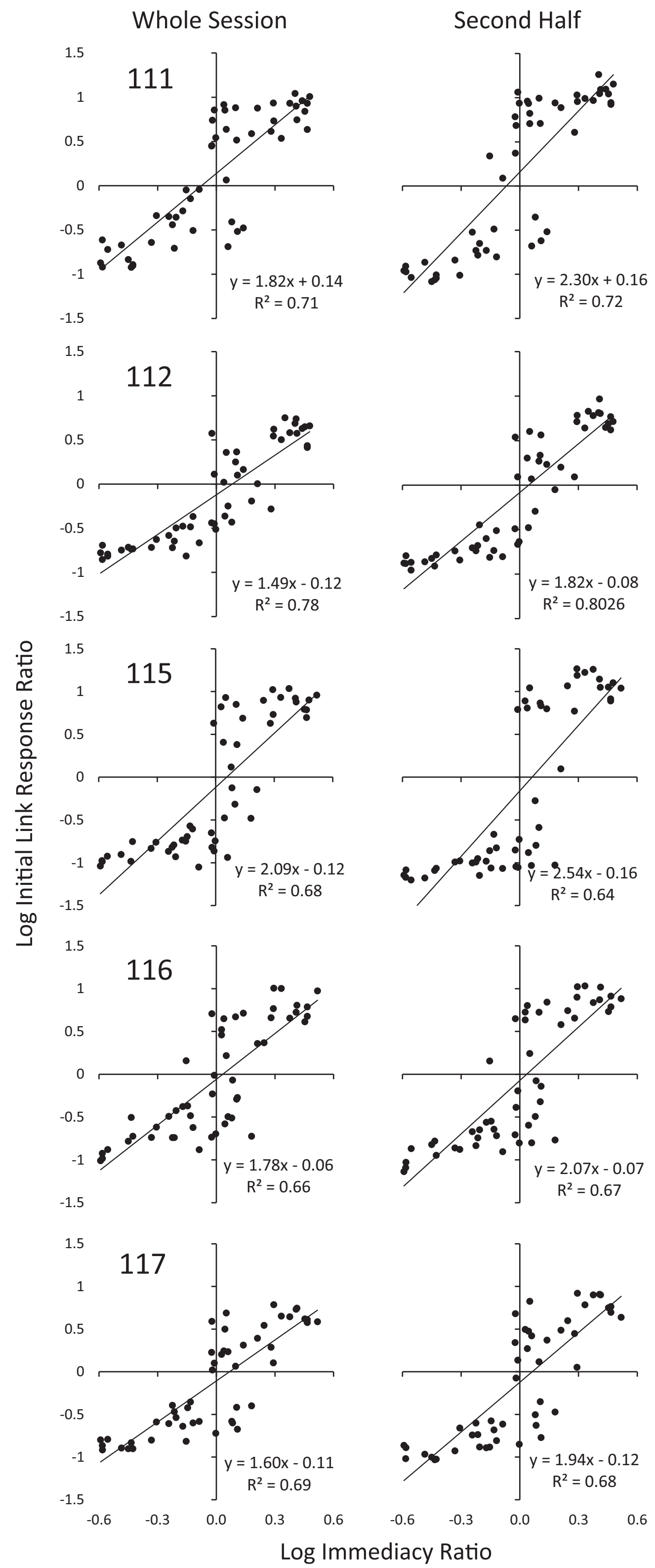

Fig. 1. Log initial-link response ratios overmatched terminal-link immediacy ratios from the maximal-variation condition of Kyonka and Grace (2007) for individual subjects. Each data point represents performance from a single session. Parameters and variance accounted for (VAC) by linear regression (solid lines) are also shown.

Fig. 1 shows log initial-link response ratios plotted as a function of log terminal-link immediacy ratios for five pigeons over 50 sessions of Kyonka and Grace's maximal-variation condition. Graphs in the left column show log response ratios computed for