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Assessing the effects of brief stimuli unrelated to reinforcement

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Abstract

Reinforcers are environmental events defined by their effects on behavior. However, brief, arbitrary stimuli can also have reinforcement-like effects, despite being unrelated to food reinforcement. The present thesis explored the potential reinforcement-like effects of brief stimuli across five experiments. In Experiments 1 through 4, pigeon subjects responded for food reinforcement and brief stimulus presentations in a two-component multiple schedule. Neither baseline response rates nor resistance to change during disruption tests were systematically greater in a component with versus without brief stimulus presentations. Additionally, increasing the rate and duration of brief stimulus presentations in Experiment 4 failed to reveal reinforcement-like effects when compared directly with food. In Experiment 5, pigeons chose between independent terminal links in a concurrent-chains procedure. Across conditions, varying the location, duration, and rate of brief stimulus presentations in the terminal links had no systematic effects on preference. In contrast, varying rates of food reinforcers resulted in large and reliable shifts in preference. Therefore, the present thesis did not find any evidence that brief stimuli unrelated to food reliably increase response rates, resistance to change, or preference. These data demonstrate the value of systematic replication, and a behavioral momentum approach to assessing potential reinforcement-like effects.

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Chapter 1

1.1   Reinforcement and measuring response strength

The behavior of organisms is shaped and maintained by environmental events. Of the numerous events an organism encounters, some are defined as reinforcers – events which increase the probability of the response that precede them (Thorndike, 1911; Skinner, 1938). While this functional definition distinguishes reinforcers from other environmental stimuli, it is also circular: Events that increase the probability of a response are reinforcers, and the probability of a response is increased by reinforcers. Therefore, it is difficult to specify *a priori* what stimulus will serve as a reinforcer without manipulating the contingencies between a response and a particular stimulus (see Critchfield & Miller, 2017; Killeen & Jacobs, 2017; Shahan, 2017, for recent discussions).

A common strategy to circumvent the circularity of the functional definition of reinforcers is to invoke the hypothetical construct of *response strength* (e.g., Skinner, 1938). From this perspective, reinforcers are thought to strengthen a response, and thereby increase the probability of that response being emitted. However, a consequent issue is the question of how response strength can be accurately measured; that is, what reliable behavioural measure can index the extent to which responses are strengthened by different rates or magnitudes of reinforcement (Herrnstein, 1970; Nevin, 1974).

The present thesis aims to assess the effects of brief stimulus events which seem to have reinforcement-like effects on behaviour. Therefore, the present chapter will review selected theoretical frameworks describing the effects of reinforcers on behavior, and the common measures used to index the 'strengthening' effects of reinforcers.

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1.2   Absolute and relative response rate

Skinner (1938) theorised that reinforcers strengthen responses by building up a reserve of responses (see Catania, 2005; Killeen, 1988, for similar models). The size of the reserve could then be indexed by the frequency with which responses were emitted from the reserve. Therefore, Skinner suggested that "the rate of responding is the principle measure of the strength of an operant [response]" (pp. 58). From this perspective, responses that had been strengthened by higher rates of reinforcement should also occur at higher rates. However, the absolute rate of responding does not correspond with the rate of reinforcement (see e.g., Morse, 1966). Instead, numerous studies show that absolute response rates are a negatively accelerated function of the reinforcer rate; response rates reach a maximum and remain flat at higher reinforcer rates (e.g., Catania & Reynolds, 1968). Therefore, the absolute rate of responding is not an accurate indicator of response strength.

Herrnstein (1970) quantified the effects of reinforcer rate on response rate with the equation:

$$B = \frac{kR}{R + R_e} \tag{1.1}$$

where B is the rate of responding, R is the rate of reinforcement. k is a parameter representing the asymptotic response rate, and R_e is a parameter representing the rate of extraneous reinforcement obtained from responses other than that being measured (i.e., other than B). This hyperbolic function describes the increase in response rates as the rate of reinforcement increases; responding increases quickly at first and then levels off below the asymptote (k) at higher reinforcer rates. The effect of the reinforcer rate on response rate is modulated by the rate of extraneous reinforcers; as R_e increases, the organism allocates more time engaging in activities other than the target (measured) response. Thus, when R_e is low, responding approaches the asymptote faster than when R_e is high.

The inclusion of R_e in Herrnstein's (1970) equation marks a departure from using the absolute rate of responding to measure response strength (cf. Skinner, 1938). Instead, response strength under Herrnstein's model is measured by *relative* response rates – the rate of a target response relative to all other responses that are available in a 'context' of reinforcement. Because all behaviours occur in the context of concurrently available alternatives, this framework suggests that response strength should be assessed by relative response rates rather than absolute response rates.

An explicit demonstration of the utility of relative response rates is to arrange two responses that are concurrently available (i.e., a *concurrent schedule*) and vary the rates of reinforcement between the alternatives across conditions (e.g., Catania, 1963; Herrnstein, 1961). In this situation, the allocation of responding across the two alternatives (hereafter *preference*) can be described by:

$$\frac{B_1}{B_2} = \frac{R_1}{R_2} \tag{1.2}$$

where B_1 and B_2 are the rates of responding to alternatives 1 and 2, respectively, and R_1 and R_2 are the corresponding rates of reinforcement obtained from the two alternatives. This equation states that the ratio of response rates *matches* the ratio of reinforcer rates. Therefore, a one-unit increase in the reinforcer ratio is predicted to result in an equivalent one-unit increase in the response ratio. This model allows researchers to compare the extent to which two responses are differentially 'strengthened' by different parameters of reinforcement (see Baum & Rachlin, 1969). In addition, the model highlights the limitation of using the absolute response rate as a measure of response strength; when the total response output is near or at asymptote (i.e., if $B_1 + B_2 = k$), increasing the rate of reinforcers for one response (e.g., R_1) will decrease the rate of another response (e.g., B_2).

Herrnstein's (1961; 1970) use of relative response rates to measure the effects of reinforcement has been developed and extended to a wealth of different procedures and research questions (see Davison & McCarthy, 1988, for review). Notably, relative response rates also tend to vary systematically with relative reinforcer rates when response alternatives are available successively, as in a *multiple schedule* (e.g., Lander & Irwin, 1968). In a typical multiple-schedule procedure, responses are reinforced in the presence of distinctive stimuli (hereafter *discriminative stimuli*), which signal different response-consequence contingencies and alternate within experimental sessions. When different rates of reinforcement are arranged in each component of the multiple schedule, relative response rates across components generally increase with increases in the relative reinforcer rate (e.g., Lobb & Davison, 1977). However, relative response rates do not *match* relative reinforcer rates. Rather, the ratio of response rates across components is typically less extreme than the ratio of reinforcer rates (see McSweeney, Farmer, Dougan, & Whipple, 1986, for review).

Numerous datasets using concurrent and multiple schedules refute the assumption that response ratios strictly match the reinforcer ratio (e.g., Alsop & Elliffe, 1988; Davison & Elliffe, 2000; Elliffe & Davison, 1985; Lobb & Davison, 1977; Staddon, 1968). Instead, relative response rates in both concurrent and multiple schedules can be more accurately described by a generalised version of Equation 1.2 (Baum, 1974; Lander & Irwin, 1968):

$$\log \frac{B_1}{B_2} = a \log \frac{R_1}{R_2} + \log c \tag{1.3}$$

where all terms are as in Equation 1.2, the parameter a scales the effect of the reinforcer ratio on the response ratio, and $\log c$ captures any inherent bias between the alternatives independent of the obtained reinforcer ratio. This equation describes a linear relation between the logarithmic transformations of response and reinforcer ratios across two alternatives,

where *a* is the slope of the line and log *c* is the intercept. When $a = 1$ and log $c = 0$, Equation 1.3 is equivalent to Equation 1.2.

The slope (*a*) in Equation 1.3 has been aptly described as the *sensitivity* parameter (Lobb & Davison, 1975), and can be used to index the extent to which the log response ratio changes as the log reinforcer ratio is varied. When the sensitivity value is less than 1.0, response ratios are said to *undermatch* the reinforcer ratio (Baum, 1974). When the sensitivity value is greater than 1.0, response ratios are said to *overmatch* the reinforcer ratio (e.g., Elliffe & Davison, 1985; 1996). Sensitivity values are generally higher in concurrent schedules than in multiple schedules (McSweeney et al., 1986). Additionally, a number of experimental manipulations can affect sensitivity values directly (e.g., Baum, 1982; Davison & Elliffe, 2000; Elliffe & Davison, 1996; Elliffe, Davison, & Landon, 2008; Miller, Saunders, & Bourland, 1980). Although *a* can vary across experimental manipulations, it provides a convenient index for the extent to which relative reinforcer rates affect relative response rates.

The utility of the sensitivity parameter has been demonstrated by numerous studies varying different parameters of reinforcement (see Davison & McCarthy, 1988, for review). Systematically varying parameters like the magnitude, quality, or delay of reinforcement across conditions yields different sensitivity values, which can be used to index the extent to which each parameter affects relative response rates (but see Elliffe, Davison, & Landon, 2008). Equation 1.3 has since been extended and integrated into a range of models for different procedures and research areas (e.g., Davison & Tustin, 1978; Grace, 1994; McLean & White, 1983). The central idea behind these models is that relative response rates are a function of relative reinforcer rates. From a 'strengthening' perspective, the sensitivity parameter can be used to index the extent to which responses are strengthened by different parameters of reinforcement.

1.3   Resistance to change

Nevin (1974) argued against using the rate of responding to measure response strength, because response rate can be shaped by various pacing schedules (e.g., Fath, Fields, Malott, & Grossett, 1983; Lattal, 1989; Nevin, 1974; Tarpy & Roberts, 1985). These pacing schedules make reinforcers contingent on a burst of responses or long pauses between responses, thereby inflating or depressing, respectively, the overall response rate. Furthermore, when reinforcers are contingent on the number of responses (i.e., arranged on *ratio* schedules), response rates and reinforcer rates are directly proportional; higher response rates result in higher obtained reinforcer rates. In contrast, when reinforcers are contingent on a response after some period of time has elapsed (i.e., arranged on *interval* schedules), higher response rates do not necessarily produce higher reinforcer rates beyond very low response rates (Baum, 1973). Therefore, Nevin argued that response rates are the product of both reinforcement and the contingencies of reinforcement, and not a pure measure of the 'strengthening' effects of reinforcers (see also Morse, 1966).

As an alternative measure, Nevin (1974) suggested that response strength could be better indexed by the persistence of a response during conditions of disruption (hereafter *resistance to change*). He demonstrated the utility of resistance to change using pigeon subjects in a two-component multiple schedule. Each component was signalled by different colours projected onto the response key, and arranged a different rate of reinforcement for key-peck responses. A variable interval (VI) 60-s schedule operated in one component; food reinforcers would be presented for a key-peck at variable intervals with a mean of 60 s. A VI 180-s schedule operated in the other component, thereby arranging a lower (or leaner) rate of reinforcement for key-peck responses. After response rates stabilised during baseline conditions, Nevin assessed resistance to change by introducing two disruption tests: response-independent food presentations during the key-dark periods between components (i.e., the

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inter-component interval, or ICI), and, in a later condition, withholding food for responses

(i.e., *extinction*). Response rates decreased in both components during each disruption test, but

to a lesser extent in the component arranging a higher reinforcer rate. Therefore, responding

was more *resistant to change* after training with a higher reinforcer rate, suggesting that

resistance to change could serve as an appropriate measure of the 'strengthening' effects of

reinforcement.

Resistance to change has since been developed and integrated into a modern

conceptualisation of reinforcement known as behavioral momentum theory (Nevin, Mandell,

& Atak, 1983; Nevin & Grace, 2000a). Behavioral momentum theory draws an analogy

between behavioural and physical momentum. The momentum of a physical object moving

through space is the product of two independent properties: velocity and mass. When an

external force (f) is applied to a moving object, the change in velocity (ΔV) is inversely

proportional to the mass (m) of the object:

$$\Delta V = \frac{f}{m} \hspace{4cm} (1.4)$$

Therefore, the velocity of objects with greater mass will change to a lesser extent when the

same external force is applied. Similarly, behaviour is thought to have velocity-like and mass-

like properties, reflected in response rates and resistance to change, respectively. When some

disruptive force (x) is introduced to decrease response rates, the change in response rates (ΔB)

is determined by the mass-like aspect of the response (m):

$$\Delta B = \frac{-x}{m} \hspace{4cm} (1.5)$$

where the sign of x is negative because any disruptive force is assumed to decrease response

rate. In order to compare changes in response rates across responses with different pre-

disruption rates, ΔB is typically expressed as a proportion of baseline response rates: B_x/B_o,

where B_x is the response rate during disruption and B_o is the response rates during pre-

disruption baseline. This proportion is then log transformed and Equation 1.5 can be rewritten as:

$$log\frac{B_x}{B_o} = \frac{-x}{m} \tag{1.6}$$

The parameter *m* represents response strength, the mass-like aspect of the response. Because responses are thought to be strengthened by reinforcers, *m* is a function of the rate of reinforcement during baseline training, and Equation 1.6 can be rewritten as:

$$log\frac{B_x}{B_o} = \frac{-x}{r^a} \tag{1.7}$$

where all terms are as in Equation 1.6, *r* is the baseline rate of reinforcement, and the parameter *a* scales the effects of reinforcement on resistance to change (see Nevin & Grace, 2000a, for discussion). Therefore, resistance to change is a function of the magnitude of disruption and the reinforcer rate during baseline; higher rates of reinforcement result in greater resistance to change.

Just as velocity and mass are independent properties in physical momentum, behavioral momentum theory suggests that response rates and resistance to change are determined by independent and separable processes (Nevin & Grace, 2000a). The relation between the response and reinforcer (hereafter *response-reinforcer* relation) determines response rates, whereas the relation between the discriminative stimulus and reinforcement (hereafter *stimulus-reinforcer* relation) determines resistance to change. Therefore, higher rates or greater magnitudes of reinforcement for a particular response will increase baseline response rates, whereas higher rates or greater magnitudes of reinforcement obtained in the presence of a discriminative stimulus will increase resistance to change (see Nevin, Craig, Cunningham, Podlesnik, Shahan, & Sweeney, 2017; Nevin & Grace, 2000a; Nevin & Shahan, 2011; Nevin & Wacker, 2013, for reviews).

Nevin, Tota, Torquato, and Shull (1990) showed that response rates and resistance to change are determined by separable processes, using a multiple-schedule procedure with pigeons. In one condition, both components of a two-component multiple schedule arranged equal VI 60-s schedules of food reinforcement. However, additional response-independent food presentations were also arranged on a variable time (VT) schedule in one component (the *Rich Component*) and not the other (the *Lean Component*). Consistent with behavioral momentum theory, and with Equation 1.1, baseline response rates were lower in the Rich than the Lean Component. However, when Nevin et al. then assessed resistance to change by disrupting responding with access to food before experimental sessions (*pre-session feeding*) and extinction, resistance to change was reliably greater in the Rich than the Lean Component. These data suggest that additional food presentations degrade the response-reinforcer relation when those reinforcers are not contingent on the target response, but enhance the stimulus-reinforcer relation by increasing the overall rate of reinforcement obtained in the presence of that discriminative stimulus. Therefore, response rates and resistance to change are determined by separable processes; the response-reinforcer and stimulus-reinforcer relations, respectively.

Nevin et al.'s (1990) findings have been replicated a number of times over a range of species, responses, and reinforcers (see Nevin & Shahan, 2011; Nevin & Wacker, 2013, for reviews). Although a number of datasets challenge the independence of the two measures (e.g., Cançardo, Abreu-Rodrigues, Aló, Hauck, & Doughty, 2017; Lattal, 1989; Nevin, Grace, Holland, & McLean, 2001; Podlesnik, Jimenez-Gomez, Ward, & Shahan, 2006; Podlesnik & Shahan, 2008), behavioral momentum theory refines our understanding of the effects of reinforcement by specifying the relations that determine response rates and resistance to change.

1.4   *Preference and resistance to change*

A further extension of behavioral momentum theory is the unifying assertion that resistance to change and response allocation between concurrently available alternatives (i.e., *preference*) are convergent measures of response strength (Nevin & Grace, 2000a). Nevin (1979) first noted the correlation between resistance to change and preference in concurrent-chains schedules. A typical concurrent-chains procedure is shown in Figure 1.1. Subjects initially choose between two concurrently available alternatives (the *initial link*). Responses to these alternatives are intermittently reinforced with access to mutually exclusive components, or *terminal links*. These terminal links are signalled by different stimuli and arrange different schedules of primary reinforcement (e.g., food). Therefore, choice between the two alternatives in the initial link reflects the subject's preference for the reinforcement schedules arranged in the terminal links (Autor, 1969). Concurrent-chain schedules are similar to the multiple-schedule procedures commonly used in research on resistance to change, and provide a situation in which the subject can choose between multiple-schedule components (Nevin, 1979). Therefore, both concurrent chains and multiple schedules can be used to assess the association between discriminative stimuli and reinforcement, using different measures – preference and resistance to change, respectively.

Initial Link

Alt. 1   Alt. 2

0.5-s on/off   0.5-s on/off

On

On

Terminal Link 1   Terminal Link 2
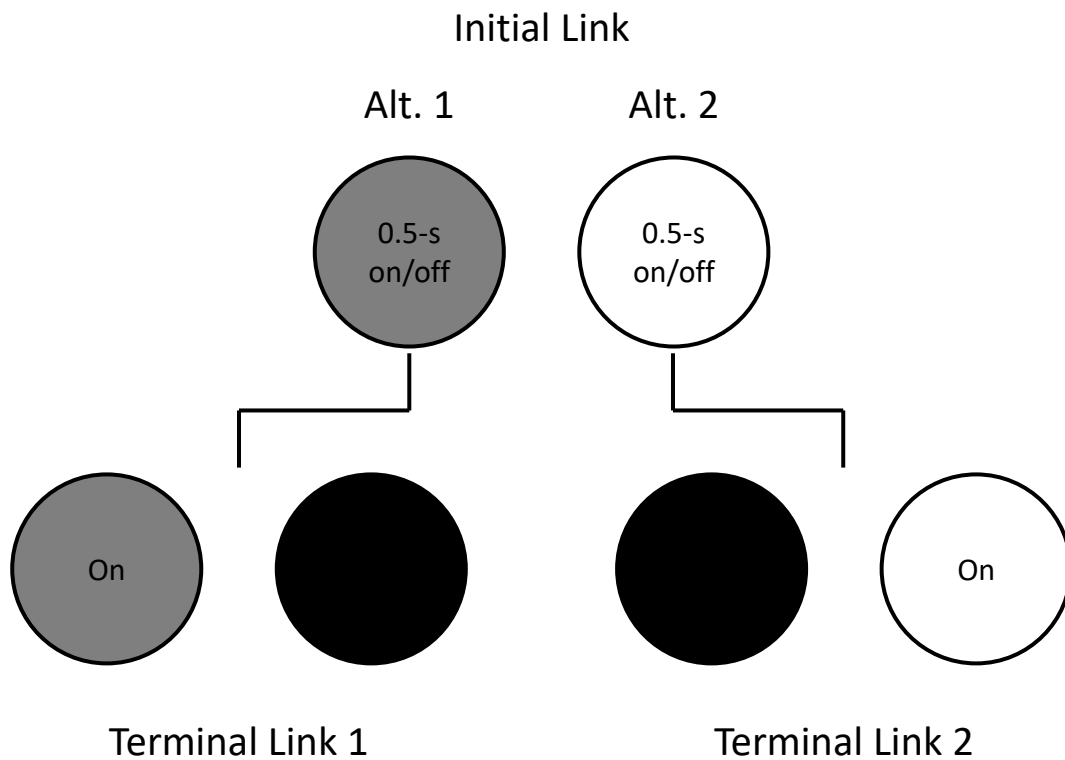
Figure 1.1. Diagram of typical concurrent-chains procedure, with the specific stimuli used in Experiment 5. Shaded and unshaded circles represent response keys lit yellow and white, respectively. During initial links, both keys flashed on/off every 0.5 s. During terminal links, only one key was lit constantly and the other was darkened.

Nevin's (1979) observations that preference and resistance to change are correlated have been developed and integrated into behavioral momentum theory. Nevin and Grace (2000a) suggest that preference and resistance to change are convergent measures of the same underlying construct – variously referred to as "response strength" or "mass" from behavioral momentum theory, and "conditioned reinforcement value" in theories of concurrent chains (e.g., the contextual-choice model; Grace, 1994). When two responses are reinforced at different rates in the presence of two discriminative stimuli in a multiple schedule, the relation between relative resistance to change and relative reinforcer rates can be described by a power function, expressed in its simplest form as:

$$\frac{m_1}{m_2} = \left(\frac{R_1}{R_2}\right)^{a_m} \qquad (1.8)$$

where m_1 and m_2 represent resistance to change in Components 1 and 2, respectively, and R_1

and R_2 represent reinforcer rates in the corresponding components. The parameter a_m scales

the effect of the reinforcer ratio on relative resistance to change, and is referred to as a

sensitivity parameter. Similarly, the relation between preference in the initial link of a

concurrent-chains schedule and relative reinforcer rates obtained in the presence of the

terminal link stimuli can also be described by a power function, expressed in its simplest form

as:

$$\frac{B_{i1}}{B_{i2}} = \left(\frac{R_{t1}}{R_{t2}}\right)^{a_r} \qquad (1.9)$$

where B_{i1} and B_{i2} represents the response rates in the initial link to Alternatives 1 and 2,

respectively, and R_{t1} and R_{t2} represent reinforcer rates in the corresponding terminal links. The

parameter a_r is the sensitivity parameter and indexes the extent to which relative responding

changes as the relative reinforcer rate varies. Equation 1.9 is similar to Equation 1.3, and can

be derived from Grace's (1994) contextual choice model with a number of assumptions,

namely 1) no bias towards either of the alternatives, 2) equal exposure to the two terminal

links, and 3) constant initial-link and terminal-link durations (see Grace & Nevin, 1997, 2000;

Nevin & Grace, 2000b, for further discussions). Therefore, both relations can be described by

power functions, and the similarity between the two functions is taken as evidence that

preference and resistance to change reflect the same underlying construct (see Nevin & Grace,

2000a, 2000b).

Grace and Nevin (1997) demonstrated the relation between preference and resistance

to change within subjects and within experimental sessions. In their procedure, each session

was divided into two halves; one half consisted of a multiple-schedule procedure, and the

other consisted of a concurrent-chains procedure. In the multiple-schedule procedure, two components were signalled by different stimuli, arranged different rates of reinforcement, and ended after a single reinforcer. The same stimuli and reinforcer rates were used in the concurrent-chains procedure. Pigeons chose between two concurrently available alternatives in the initial link, and were reinforced with access to mutually exclusive terminal links, signalled by the same stimuli used in the multiple-schedule procedure. Food reinforcers in the terminal links were scheduled at the same rate as in the multiple schedule, and ended after a single reinforcer. Therefore, the relation between the discriminative stimuli and reinforcement remained constant across both procedures. Across conditions, the experimenters varied the rates of reinforcers in each component/terminal link, and used response-rate ratios in the initial link of the concurrent-chains procedure to assess preference between the two terminal links. Additionally, they disrupted responding in the multiple-schedule procedure using ICI-food tests to assess resistance to change.

Grace and Nevin (1997) found orderly relations in both preference and relative resistance to change as the relative reinforcer rates varied parametrically across conditions. Preference, measured as the log ratio of response rates in the initial link, was a linear function of the log ratio of reinforcer rates in the terminal links, accurately described by a logarithmic form of Equation 1.9:

$$\log\frac{B_{i1}}{B_{i2}} = a_r \log\left(\frac{R_{t1}}{R_{t2}}\right) + \log c_r \qquad (1.10)$$

Where all terms are as in Equation 1.9, the parameter a_r scales the effect of the reinforcer ratio on response allocation and $\log c_r$ captures any inherent bias between the alternatives independent of the obtained reinforcer ratio. This equation has historical roots in Equation 1.3 and is hereafter referred to as a *generalised matching analysis*. The slope a_r is also referred to as *sensitivity* (Lobb & Davison, 1975). As with Equation 1.3, a sensitivity value of 1.0

indicates that a one-unit change in the log reinforcer ratio produces an equivalent one-unit change in log response ratio (i.e., the response ratio *matches* the reinforcer ratio).

Relative resistance to change, measured as the difference in log proportion of baseline response rates, was also a linear function of the log ratio of reinforcer rates. These data were similarly well described by a logarithmic form of Equation 1.8:

$$\log\frac{B_{x1}}{B_{o1}} - \log\frac{B_{x2}}{B_{o2}} = a_m\log\left(\frac{R_1}{R_2}\right) + \log c_m \qquad (1.11)$$

where B_o is the response rate during baseline, B_x is the response rate during disruption, R is the reinforcer rate, and subscripts 1 and 2 differentiate the two components. Similar to a_r in Equation 1.10, the parameter a_m scales the effect of the reinforcer ratio on relative resistance to change. The log c_m parameter captures any inherent bias independent of the obtained reinforcer ratio. Although both preference and relative resistance to change were controlled by the reinforcer ratio, Grace and Nevin (1997) found much greater sensitivity values for preference ($M = 0.91$, *range* = 0.83-1.05) than relative resistance to change ($M = 0.20$, *range* = 0.09-0.39). This shows that preference changes to a greater extent than relative resistance to change when the reinforcer ratio is varied. Therefore, although both preference and resistance to change are determined by relative reinforcer rates, preference is a more sensitive measure of differences in reinforcement rates.

Grace and Nevin (1997) arranged multiple-schedule components and terminal links that ended after a single reinforcer, as is typical of standard concurrent-chain research (e.g., Jimenez-Gomez & Shahan, 2012). In contrast, typical multiple-schedule research arrange components for a constant duration and multiple reinforcers can be obtained in each component (e.g., Nevin, 1974). In a subsequent experiment, Nevin and Grace (2000b) replicated Grace and Nevin's (1997) study using constant duration multiple-schedule components and terminal links. These constant-duration periods gave access to the VI food

schedule for 30 s, so that pigeons could obtain zero, one, or multiple reinforcers per terminal link. They replicated Grace and Nevin's general findings, confirming a positive relation between preference and resistance to change, and greater sensitivity values for preference than resistance to change. However, the mean sensitivity value was 1.78 for preference and 0.62 for relative resistance to change, much higher than the values found by Grace and Nevin using variable-duration components. Therefore, relative responding (both preference and resistance to change) changed to a greater extent when relative reinforcer rates were varied in a constant-duration procedure, compared with a variable-duration procedure, a finding confirmed within subjects and within sessions by Grace and Nevin (2000).

If sensitivity is taken as an index of how different reinforcement rates 'strengthen' different stimulus-reinforcer relations, the findings above suggest that preference in a concurrent-chains procedure is a more sensitive measure than resistance to change to detect the effects of different reinforcement rates on behaviour. Furthermore, the sensitivity of both measures can be enhanced using constant-duration, rather than variable-duration, components and terminal links.

1.5   Summary

If reinforcers are assumed to enhance response strength, then any measurement of response strength must necessarily co-vary with the parameters of reinforcement (see Baum & Rachlin, 1969; Herrnstein, 1970; Killeen, 1972; Nevin, 1974, for discussions). Although different theoretical perspectives emphasise different dimensions of behaviour to index the effects of reinforcement, the combined literature provide a quantitative framework for analysing the 'strengthening' effects of reinforcement. While the analytic tools reviewed above do not resolve the overarching issue of what defines a reinforcer, they can help us to distinguish between reinforcers and other environmental stimuli.

The present thesis attempts to assess the reinforcement-like effects of brief arbitrary stimuli, using the measures summarised above. Specifically, we use relative response rates and relative resistance to change across components of a multiple schedule (Experiments 1 through 4), and preference in a concurrent chains procedure (Experiment 5) to assess whether response-contingent brief stimuli have reliable reinforcement-like effects on behaviour. The following chapter reviews selected findings showing reinforcement-like effects of brief stimuli, and discusses the problem that such stimuli might have for a functional definition of reinforcers.

Chapter 2

2.1   On the effects of response-contingent brief stimuli

Reinforcers are differentiated from other environmental events by their effects of behaviour. However, a wide range of findings have shown that arbitrary stimuli can also have reinforcement-like effects when presented following a response (e.g., Davison & Baum, 2006; Neuringer & Chung, 1957; Stubbs, 1971). Crucially, these stimuli only affect behaviour because of some relation between brief stimulus presentations and primary reinforcers like food. More puzzling are brief stimuli which have reinforcement-like effects on behaviour when brief stimulus presentations are unrelated to food reinforcers (Reed & Doughty, 2005; Podlesnik, Jimenez-Gomez, Ward, & Shahan, 2009). These later cases challenge a functional definition of reinforcers and highlight the need for further investigation. The present chapter reviews the effects of response-contingent brief stimuli, and evaluates the findings of reinforcement-like effects of brief stimuli unrelated to primary reinforcement.

2.2   Brief stimuli related to reinforcement

A number of studies demonstrate reinforcement-like effects of arbitrary stimuli when there is a programmed relation between the brief stimulus and primary reinforcer presentations. Response-contingent brief stimulus presentations can maintain responding (e.g., Zimmerman, Hanford, & Brown, 1967), increase overall response rates (e.g., Neuringer & Chang, 1957; Reed & Hall, 1989), change local patterns of responding (e.g., Kelleher, 1966; Stubbs, 1971), shift allocation of responses between concurrently-available alternatives (e.g., Boutros, Davison, & Elliffe, 2011; Davison & Baum, 2006; 2010; Shahan, Podlesnik, & Jimenez-Gomez, 2006), and increase resistance to change (e.g., Bell, Seip, & Fitzsimmons, 2007). The processes by which these brief stimuli come to control behaviour have been

debated (see Bell & McDevitt, 2014; Davison & Baum, 2006; 2010; Kelleher & Gollub, 1962; Keller & Schoenfeld, 1950; McGill, Buckley, Elliffe, & Corballis, 2017; Schuster, 1969; Shahan, 2010; Williams, 1994). Regardless of the processes by which these stimuli come to influence behaviour (e.g., by conditioned reinforcement or signalling future reinforcer contingencies), it is generally accepted that arbitrary stimuli affect behaviour because of their relation with primary reinforcers.

The degree to which brief stimulus and reinforcer presentations are related varies across studies and procedures. A large body of research has assessed the effects of 'conditioned reinforcers'; stimuli presented in close temporal proximity to the presentation of reinforcers (see Bell & McDevitt, 2014; Keller & Schoenfeld, 1950; Williams, 1994, for reviews). However, a variety of other relations can be arranged and even tenuous relations between brief stimulus and reinforcer presentations can result in reinforcement-like effects of brief stimuli.

As an illustrative case, Neuringer and Chung (1957) found increased rates of key-peck responding in pigeons when key-pecks sometimes resulted in food reinforcers and, at other times, brief *blackout* periods, when both the key- and house-lights were turned off. Food was arranged on a VI 60-s schedule and contingent on the completion of a FI 5-s component; therefore, a response after the completion of the fixed interval would result in a food reinforcer if the concurrently timed VI 60-s schedule had timed out. However, on completion of a FI component that did not coincide with a reinforcer arranged by the VI schedule, a brief 1-s blackout was presented instead. Thus, food and blackouts were arranged on a *percentage schedule* (Ferster & Skinner, 1957), and brief blackouts were never presented immediately before food.

The presentation of brief blackouts in Neuringer and Chung's (1957) study increased response rates two-fold compared with a condition without blackouts. Furthermore, response rates only increased marginally when the brief blackouts were replaced by food reinforcers, despite an approximately eight-fold increase in the food-reinforcer rate. These results demonstrate what first appears to be a reinforcement-like effect of brief blackouts. However, replacing the blackout with a 1-s buzzer resulted in the same increased response rate. Furthermore, blackouts did not increase response rates when arranged on a fixed-ratio (FR) 11 schedule. Therefore, the blackouts did not have inherent reinforcement-like effects. Instead, blackouts increased response rates via their relation with food; only when both food and blackouts were produced by the same contingencies did blackouts increase response rates (see also Stubbs, 1971). Therefore, Neuringer and Chung's study demonstrates that even a weak relation between brief stimulus and food presentations can result in reinforcement-like effects. Nevertheless, the effects of the brief stimuli required a relation between brief stimulus and reinforcer presentations.

2.3   Brief stimuli unrelated to reinforcement

Given that brief stimuli influence behaviour through some relation with primary reinforcers, surprising findings come from a study by Reed and Doughty (2005). They found that stimuli with no programmed relation to food reinforcers can also have reinforcement-like effects. In their study, rats were trained to press levers in a two-component multiple schedule. Lever pressing in both components was reinforced by food pellets on equal random-interval (RI) 60-s schedules of reinforcement. In one component, brief 0.5-s tones were also arranged on an independent RI 60-s schedule, operating on the same lever (technically a *conjoint schedule*; see Imam & Lattal, 1992). Therefore, responses in that component sometimes resulted in food and, at other times, brief tones. However, the distributions of food and tones were random in time and independent of one another, such that there was no relation between

food and tone presentations. Across all four rats, response rates were higher in the component arranging additional tone presentations. Furthermore, when responding was disrupted with ICI-food and extinction tests, responding was also more resistant to change in the component arranging additional tone presentations. The increased response rates and resistance to change mirror the effects of additional food reinforcers (e.g., Nevin, 1974), and challenge the current understanding of how reinforcers are defined.

From a behavioral momentum framework, the brief tones used in Reed and Doughty's (2005) procedure increased response rates and resistance to change apparently by enhancing the response-reinforcer and the stimulus-reinforcer relations, respectively. However, the tones were not paired with the onset of food, nor did they signal anything about the contingency of food reinforcement (see Davison & Baum, 2006, 2010; Shahan, 2010, for related discussions). Therefore, it is unlikely that the tones acquired their effects on responding via some relation to food.

If the brief tones in Reed and Doughty's (2005) study did not enhance response rates and resistance to change through a relation with food reinforcers, a purely functional definition of reinforcement would classify those tones as reinforcers (see Killeen, 1972). However, these brief tones do not serve any obvious or ultimate function, e.g., increased survival or reproduction. Specifically, they are not phylogenetically important (see Baum, 2005; 2012). Furthermore, while certain stimuli might function as sensory (Kish, 1966) or perceptual reinforcers (Loovas, Newsom, & Hickman, 1987), the same tones used in Reed and Doughty's study have aversive properties when presented in concurrent-schedule procedures (Reed, Collinson, & Noakes, 1995; Reed & Yoshino, 2008). In particular, Reed and Yoshino found lower overall response rates when both levers produced both food and brief tones on conjoint VI schedules. Direct comparisons between Reed and Doughty's (2005) and Reed and Yoshino's (2008) findings are complicated by the fact that the latter arranged

brief tones in the context of a concurrent schedule, and analysed overall response rates by summing responses across both keys. Nevertheless, it appears that the same tones have reinforcement-like effects in some contexts, and aversive properties in others. Therefore, it is difficult to conclude that presentation of these tones are inherently reinforcing.

An alternative possibility is that Reed and Doughty's (2005) results are a Type I error, or due to some characteristic specific to those rats. However, these interpretations are challenged by a replication by Podlesnik, Jimenez-Gomez, Ward, and Shahan (2009). Eight pigeons, with previous experience in multiple-schedule experiments, were trained in a two-component multiple schedule, with components signalled by different colours projected onto the response keys. In both components, key-peck responses were reinforced by grain on equal VI 60-s schedules of reinforcement. In one component, brief 0.5-s changes in the response-key colour (hereafter *brief stimulus presentations*) were also arranged conjointly on a VI 60-s schedule. The use of VI rather than RI schedules likely had little effect on responding (see Millenson, 1963). As in Reed and Doughty, the distributions of food and brief stimulus presentations were random in time and independent of one another, such that there was no relation between food and brief stimulus presentations. Response rates in the two components did not differ systematically; however, responding during pre-session feeding and extinction tests was more resistant to change in the component arranging brief stimulus presentations. Therefore, Podlesnik et al. replicated the persistence-enhancing effects of brief stimuli unrelated to food with a different species (pigeons vs. rats), different responses (key pecking vs. lever pressing), and different stimuli (visual vs. auditory).

At first glance, Podlesnik et al.'s (2009) results seem to support the generality of Reed and Doughty's (2005) findings, and suggest that brief, arbitrary stimuli unrelated to reinforcement can have some reinforcement-like effects on behaviour. However, Podlesnik et al. did not find any differences in response rates or resistance to change between groups with

low versus high rates of brief stimulus presentations (arranged on VI 60-s and VI 15-s schedules, respectively). This differs from the effects of food reinforcers, which generally increase both response rates and resistance to change when presented at higher rates (e.g., Nevin, 1974). Furthermore, when comparing the different rates of stimulus presentations within subjects and across components of a multiple schedule, responding in the component with a higher rate of brief stimuli was systematically *less* resistant to change. These findings challenge the idea that brief stimuli affect responding in the same manner as food reinforcement. Conversely, the potential reinforcement-like effects of brief stimuli unrelated to food reinforcement challenge the functional definition of reinforcers, and highlight the need for further exploration.

2.4   Summary

A number of studies demonstrate reinforcement-like effects of brief response-contingent stimuli when there is a relation between brief stimulus and reinforcer presentations. However, the results of Reed and Doughty (2005) and Podlesnik et al. (2009) challenge our understanding of reinforcers and reinforcer-related stimuli by demonstrating reinforcement-like effects of brief stimuli unrelated to reinforcement.

The present thesis aims to assess the effects of brief stimulus presentations unrelated to reinforcement, and examine whether these stimuli have replicable, reinforcement-like effects on behaviour. To this end, we implement the analytic tools developed by previous theoretical and quantitative models, and reviewed in Chapter 1. Specifically, Experiments 1-3 attempted to replicate Reed and Doughty (2005) and Podlesnik et al. (2009), and assess whether an additional schedule of brief stimulus presentations systematically increase response rate or resistance to change. Experiment 4 then examined whether increases in the rate or duration of brief stimulus presentations would enhance the effects of brief stimuli.

Lastly, Experiment 5 used a concurrent-chains schedule to examine whether pigeons preferred schedules of reinforcement with versus without additional brief stimulus presentations.

Chapter 3

3.1   Experiment 1

The purpose of Experiment 1 was to replicate and extend Podlesnik et al.'s (2009) procedure with pigeons. Podlesnik et al. assessed relative response rates and resistance to change in a single condition, across components with versus without an additional schedule of brief stimulus presentations. The current experiment extended their study by arranging three conditions and varying the location and presence/absence of brief stimulus presentations. In all conditions, we arranged food reinforcers on equal VI 60-s schedules in both components of a two-component multiple schedule. The conditions differed in terms of whether, and in which component, we also arranged brief stimulus presentations on an additional VI 60-s schedule (Table 3.1). The programming and rates of food and brief stimulus presentations were identical to that used in Podlesnik et al.'s experiment.

3.2   Method

3.2.1   Subjects

The subjects were 6 pigeons, numbered 51 to 56, maintained at 85% ± 15 g of their free-feeding weights by post-session supplementary feeding of mixed grain. Water and grit were freely available at all times. Pigeons were housed in a colony room with a shifted light-dark cycle, with lights turned on at midnight and off at 4 pm. Experimental sessions ran 7 days a week at 1 am and no personnel were present during sessions.

3.2.2   Apparatus

The pigeons' home cages also served as experimental chambers. The chambers were 375 mm high, 380 mm wide, and 380 mm deep. The floor, ceiling and front wall were constructed from steel bars, and the other walls were constructed from sheet metal. Four

translucent response keys, measuring 20 mm in diameter, were mounted in a horizontal row on the right wall, 300 mm above the floor and 65 mm apart, center to center. Only the second from left and right-most keys were used (hereafter left and right, respectively). Both keys could be transilluminated white, yellow and red. Pecks to a lit key exceeding 0.1 N of force were recorded as responses. A hopper filled with wheat was situated behind a magazine aperture, located 80 mm below the response keys and measuring 55 mm high, 55 mm wide, and 40 mm deep. During reinforcement, the magazine was illuminated, the hopper was raised, and all keys were darkened for 2 s. All experimental events were programmed and recorded by a computer running MED PC® in an adjacent room.

3.2.3   Procedure

The pigeons had previous experience in a conditional discrimination procedure (unpublished) and multiple schedules (Podlesnik, Bai, & Skinner, 2016) and were introduced directly to the experiment. Each condition arranged a two-component multiple schedule, with Component 1 signalled by the left response key lit white, and Component 2 signalled by the right response key lit yellow. Each component was 60 s in duration and was preceded by a 30-s inter-component interval (ICI), during which both keys were darkened and inoperative. The first component in each session was selected randomly, and components alternated pseudo-randomly throughout the experimental session, with the constraint that the same component was presented no more than twice in succession. Each experimental session was preceded by a 30-min pre-session blackout of all keys and ran for 12 presentations of each component, or approximately 36 min. Reinforcement times were excluded from the timing of components, and calculations of response and reinforcer rates.

In all conditions, both components arranged food reinforcers on equal VI 60-s schedules, sampling from separate lists of 13 intervals (Flesher & Hoffman, 1962). Across

conditions, one component also arranged response-contingent brief stimulus presentations according to a VI 60-s schedule, which operated on the same key as food reinforcers (i.e. a conjoint schedule; see Iman & Lattal, 1992; Podlesnik et al., 2009; Reed & Doughty, 2005). During brief stimulus presentations the active response key was lit red for 0.5 s before changing back to the discriminative stimulus signalling that component. Food and brief stimuli (collectively referred to as *events*) were always arranged on independent schedules. If both events were available, the event arranged first would be presented following a response. After termination of the first event, the second event would be presented following the next response (see also Podlesnik et al., 2009). Events arranged but not presented by the end of a component were held until the next occurrence of the same component.

Table 3.1

Arranged schedules of food and brief stimulus presentations in each condition of Experiment 1.

	Food schedule		Stimuli schedule	
Condition	Comp 1	Comp 2	Comp 1	Comp 2
1	VI 60 s	VI 60 s	VI 60 s	-
2	VI 60 s	VI 60 s	-	-
3	VI 60 s	VI 60 s	-	VI 60 s

Table 3.1 shows the schedules for food and brief stimuli in each condition. In all three conditions, food reinforcers were arranged on equal VI 60-s schedules in both components. Brief stimulus presentations were arranged in Component 1 during Condition 1, removed during Condition 2, and finally arranged in Component 2 during Condition 3. Therefore, if brief stimuli have reinforcement-like effects, relative response rates and resistance to change should shift progressively towards Component 2 across conditions.

In each condition, stable baseline responding was established before disruption tests were introduced separately to assess resistance to change. Condition 1 arranged 49 sessions of baseline to establish stable response rates before the first disruption test. Stability was then

assessed by visual inspection before each disruption test (see e.g., McLean, Campbell-Tie, & Nevin, 1996; Podlesnik & Bai, 2015; Podlesnik, Bai, & Elliffe, 2012). Subsequent conditions arranged a minimum of 17 baseline sessions before the first disruption test ($M = 18.5$, $SD = 0.7$), with a minimum of 12 sessions between each disruption test ($M = 14.6$, $SD = 2.6$).

Within each condition, four disrupter tests were used to assess resistance to change: response-independent food presentations during the pre-session blackout (hereafter *prefeeding*), response-independent food presentations during the ICI (hereafter *ICI food*), extinction of food only (hereafter *extinction with stimuli*), and extinction of both food and brief stimuli (hereafter *extinction without stimuli*). Each disrupter was in effect for six consecutive sessions.

During prefeeding tests, response-independent food presentations were delivered on variable time (VT) schedules during the 30-min pre-session blackout. Three VT values were arranged, each presented for two consecutive sessions (see Bai & Podlesnik, 2017; Podlesnik & Fleet, 2014). The order of VT values was VT 10 s, VT 7.5 s, and VT 5 s. During ICI food tests, response-independent food presentations were delivered on VT schedules during the ICI. Three VT values were arranged, each presented for two consecutive sessions. The order of VT values was VT 1 s, VT 0.5 s, and VT 0.1 s. During extinction-with-stimuli tests, food presentations were withheld for 6 sessions and brief stimulus presentations continued to be presented on the VI 60-s schedule, as in baseline (see Podlesnik et al., 2009). During extinction-without-stimuli tests, both food and brief stimulus presentations were withheld for 6 sessions. In each condition, the order of the two extinction tests was randomly selected and counterbalanced across pigeons.

3.2.4   Dependent measures

Mean responses per min and events per hr during baseline were calculated by averaging across the six baseline sessions immediately preceding each disruption test. Resistance to change was calculated as the log mean proportion of baseline response rates; responses rates in each session of disruption were divided by the mean baseline response rate in the immediately preceding baseline. We then logarithmically transformed the average of all 6 sessions to obtain a single summary measure of the decrease in responding during each disruption test (see Podlesnik, Jimenez-Gomez, & Shahan, 2013).

We calculated relative measures to compare response rates and resistance to change across components. For baseline response rates, we used the log response ratio (see e.g., Barron & Davison, 1972; Charman & Davison, 1982; Lander & Irwin, 1968), calculated as: log(Component 1/ Component 2). For resistance to change, we used the difference in log proportion of baseline response rates (e.g., Bai, Chan, Elliffe, & Podlesnik, 2016; Bai & Podlesnik, 2017; Grace & Nevin, 1997; Podlesnik et al., 2016; see Nevin & Grace, 2000a, for discussion), calculated as: $\log(\text{Component } 1_{\text{Disruption}}/ \text{Component } 1_{\text{Baseline}}) - \log(\text{Component } 2_{\text{Disruption}}/ \text{Component } 2_{\text{Baseline}})$. For both relative measures, values greater than 0 indicate higher response rates or greater resistance to change in Component 1, and values less than 0 indicate higher response rates or greater resistance to change in Component 2.

3.3   Results

Mean baseline responses per min and obtained event presentations per hr are presented in Table 3.2. In general, obtained event presentation rates were slightly lower than but nevertheless approximated the scheduled rate of 60 per hr. Appendix Figures A3.1 to A3.3 present log proportion of baseline responses rates during each disruptor test in Conditions 1 through 3 as a function of successive VT values during prefeeding and ICI-food tests, and as a

function of successive sessions of extinction during extinction-with-stimuli and extinction-without-stimuli tests.

Table 3.2
Mean baseline responses per min and obtained food and brief stimulus presentations per hr in Experiment 1.

Pigeon	Condition	Responses per min		Foods per hr		Stimuli per hr	
		Comp 1	Comp 2	Comp 1	Comp 2	Comp 1	Comp 2
51	1	82.31	71.91	56.46	55.42	54.38	-
	2	76.75	79.54	53.33	56.11	-	-
	3	70.89	73.63	55.00	57.29	-	57.71
52	1	68.38	70.30	55.21	55.63	54.79	-
	2	41.30	83.86	54.72	56.11	-	-
	3	44.38	72.90	54.79	54.17	-	55.00
53	1	84.85	96.98	56.88	55.42	56.67	-
	2	90.19	114.13	54.44	56.39	-	-
	3	88.59	99.62	55.63	55.63	-	56.88
54	1	81.09	87.27	53.13	56.46	53.75	-
	2	83.43	85.36	52.78	54.44	-	-
	3	98.91	89.36	55.42	54.38	-	60.00
55	1	128.05	85.22	55.63	55.42	56.04	-
	2	139.45	87.38	55.83	54.72	-	-
	3	115.36	85.69	55.42	53.96	-	57.08
56	1	74.36	82.14	56.46	55.63	52.29	-
	2	69.71	70.18	55.56	55.56	-	-
	3	63.69	54.46	53.54	56.04	-	56.67

Figure 3.1 shows the relative measures of baseline response rates (left panel) and resistance to change (right panel) across the three conditions for individual pigeons. For relative baseline response rates, each data point represents the log response ratio in the six sessions immediately preceding each disruption test. If brief stimuli had reinforcement-like effects, data points should be above the *x*-axis (set at $y = 0$) in Condition 1, and below the *x*-axis in Condition 3. However, we did not observe this pattern; relative response rates during baseline did not systematically change across conditions with changes in presentations of brief stimuli.

For relative resistance to change in Figure 3.1 (right panel), each function represents the results of a different disruption test. Condition 2 did not arrange brief stimuli in either component and therefore we did not run an extinction-with-stimuli test. Relative resistance to change also was not systematically related to presentations of the brief stimuli. In contrast, relative resistance to change tended to be greater in Component 2 across all three conditions. In Condition 1, 22 of the 24 data points (6 pigeons x 4 disruption tests) were below 0, with the exceptions being 53 in the extinction-without-stimuli test and 54 in the prefeeding test. In Condition 2, despite both components arranging identical contingencies, 16 of the 18 data points (6 pigeons x 3 disruption tests) were below 0, with the exceptions being 52 and 53 in the ICI-food test. Therefore, pigeons appeared to be biased in resistance to change to Component 2. In Condition 3, resistance to change was again greater in Component 2 with 19 of the 24 data points being below 0. Exceptions were 52 and 53 in the ICI-food and extinction-with-stimuli tests, and 54 in the prefeeding test.
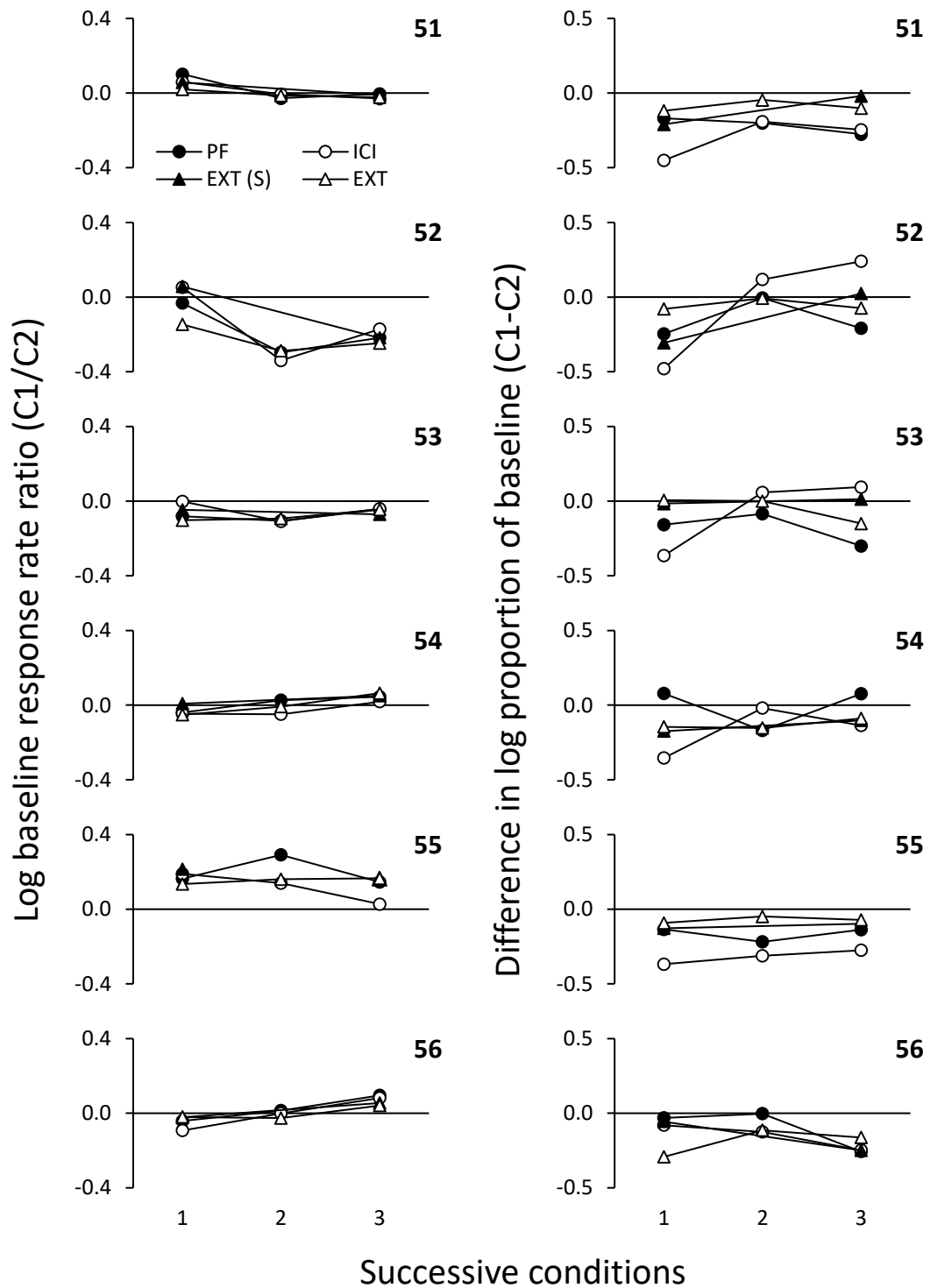
Figure 3.1. Log baseline response rate ratios (left panel) and differences in log proportion of baseline response rates (right panel) across successive conditions for individual pigeons in Experiment 1. Separate functions represent baseline response rates preceding, and resistance to change during, each disrupter test, in the left and right panels, respectively. PF refers to prefeeding, ICI refers to ICI food, EXT(s) refers to extinction with stimuli, and EXT refers to extinction without stimuli.

Similar to Podlesnik et al. (2009), we also assessed whether local response rates were higher immediately following the presentation of food versus brief stimuli. Figure 3.2 and 3.3 show the median inter-response times (IRTs) immediately before and after food and brief stimulus presentations in Conditions 1 and 3, respectively. Data for each figure were taken from the six baseline sessions preceding each of the four disruption tests (a total of 24 sessions), and IRTs were calculated from all events with five consecutive responses before and after the presentation of an event. Longer IRTs indicate lower response rates, and shorter IRTs indicate higher response rates. The IRT immediately before the presentation of either event tended to be longer because the probability of a VI interval timing out increases with longer IRTs. In both Figures 3.2 and 3.3, IRTs after food presentations (unfilled data points) were shorter than pre-food IRTs for all pigeons except 51. However, IRTs after brief stimulus presentations did not differ systematically to pre-stimulus IRTs. Therefore, local response rates increased after food but not after brief stimulus presentations (see also Podlesnik et al., 2009).

Figure 3.2. Median inter-response times (IRTs) immediately before and after food (unfilled data points) or brief stimulus presentations (filled data points) in Experiment 1 Condition 1.
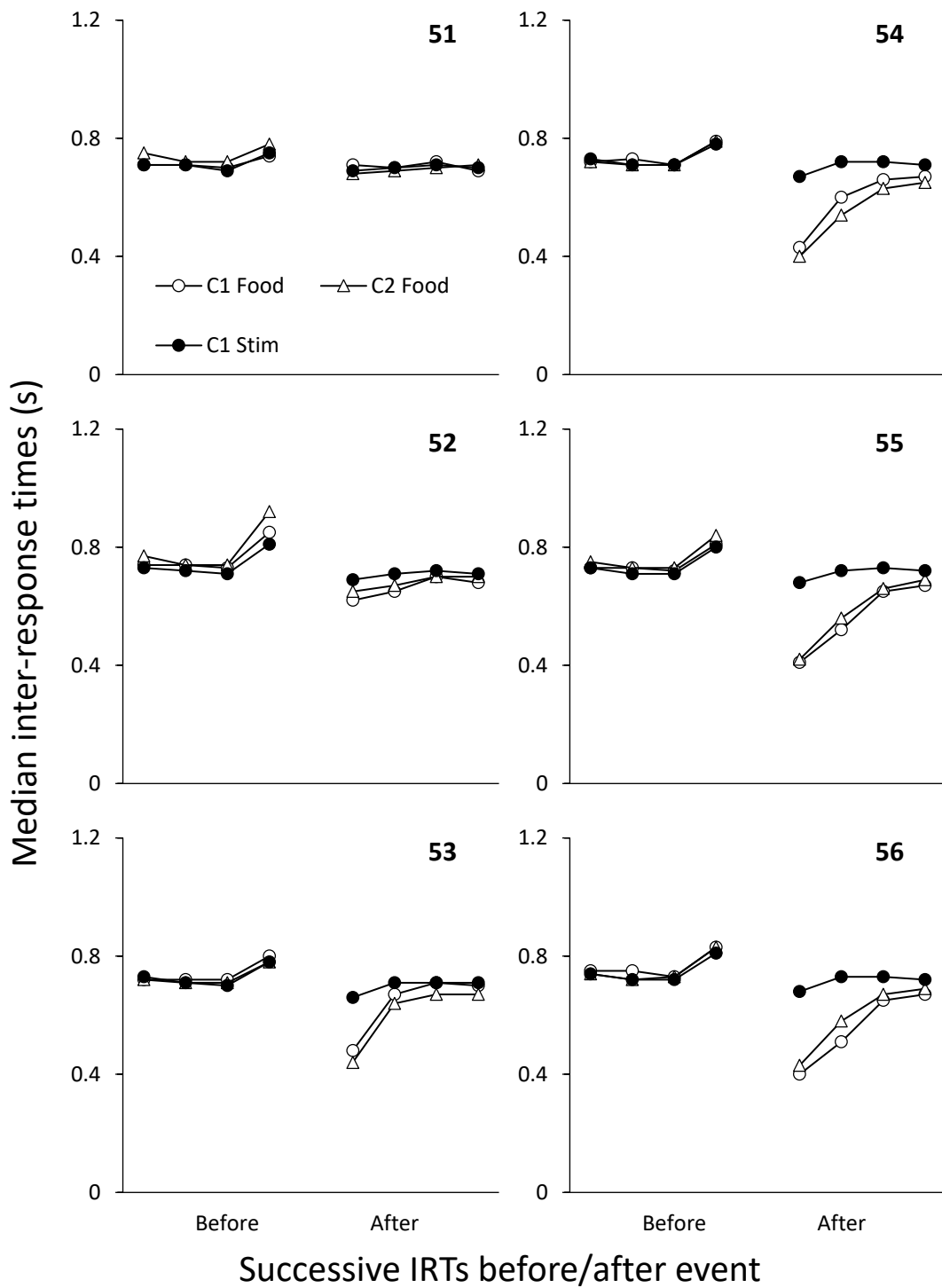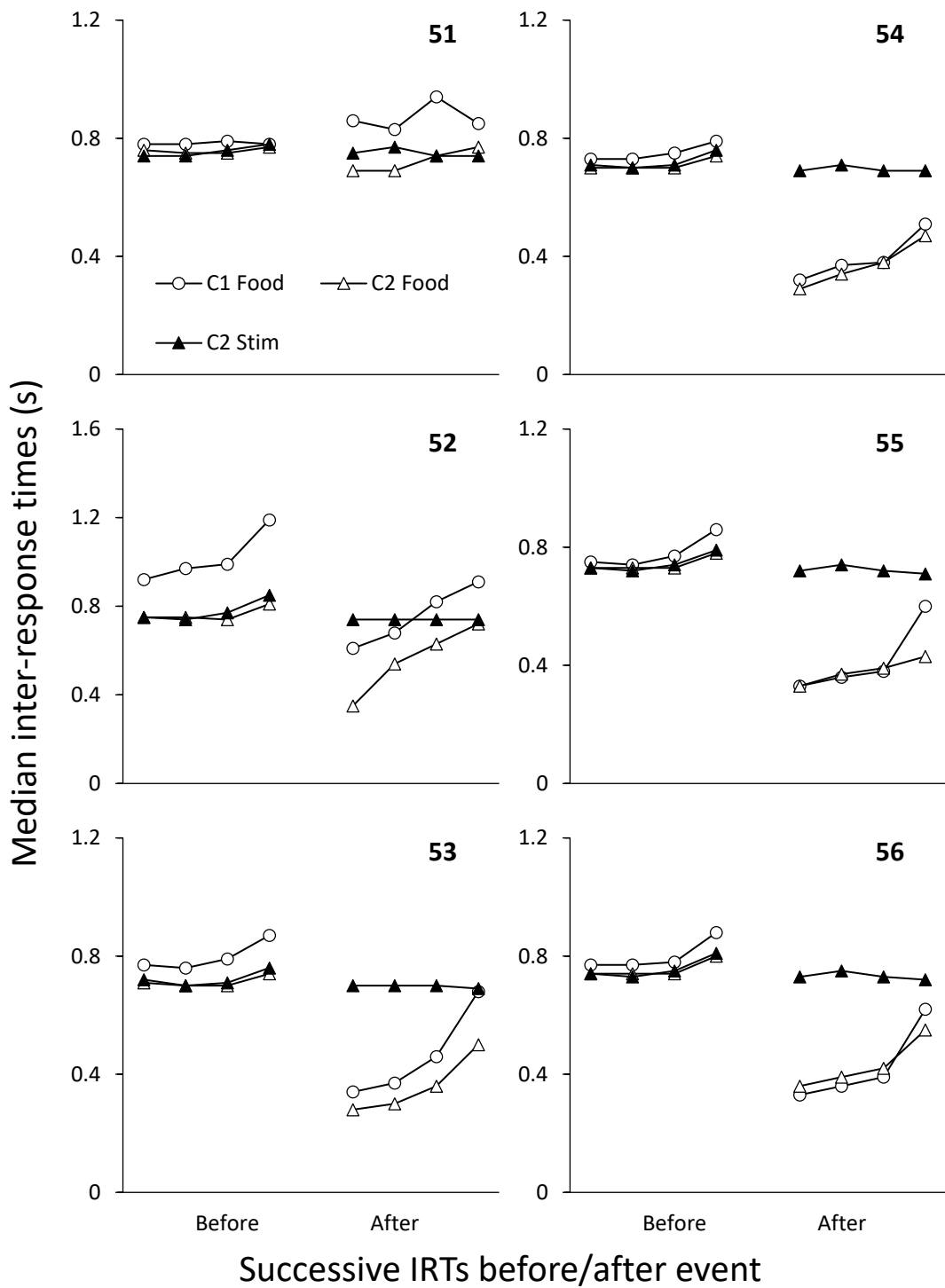
Figure 3.3. Median inter-response times (IRTs) immediately before and after food (unfilled data points) or brief stimulus presentations (filled data points) in Experiment 1 Condition 3.

3.4   Discussion

Experiment 1 failed to find reliable reinforcement-like effects of brief stimuli unrelated to food reinforcement. Response rates and resistance to change were not systematically greater in a component with versus without brief stimulus presentations. Neither measure changed systematically when the location of brief stimulus presentations was varied across conditions. Furthermore, food presentations increased local response rates but brief stimulus presentations did not. These results replicate the findings of Podlesnik et al. (2009) that brief stimulus presentations do not have systematic effects on response rates. However, the present findings are inconsistent with Podlesnik et al.'s findings in that brief stimuli in our study did not systematically increase resistance to change.

The present procedure replicated a key condition in Podlesnik et al.'s (2009) study, using the same species (pigeons), response (key pecking) and stimuli (brief changes in the colour of the response key). However, we did not find the same persistence-enhancing effects as reported in Podlesnik et al. One reason for this discrepancy was a consistent bias across conditions towards the right yellow key, as indexed by the tendency to observe greater resistance to change in Component 2. This bias towards the right yellow key is likely due to the pigeons' experimental histories. Specifically, in Podlesnik et al. (2016), the pigeons had previous experience in a multiple schedule in which left and right yellow keys signalled a concurrent VI 37.5-s VI 150-s schedule, and a left white key signalled a VI 600-s schedule. Therefore, the yellow keys were associated with an overall reinforcer rate of 120 per hr, and the left white key was associated with an overall reinforcer rate of 6 per hr. In the present experiment, the rates of food reinforcers were equal across the two components. Therefore, even if brief stimuli had strong reinforcement-like effects, the effective reinforcer rate differential between components would still be much smaller than the 20:1 reinforcer rate differential pigeons experienced in Podlesnik et al.'s study. The extreme reinforcer

differential experienced before the present experiment likely explains the consistent bias in the present resistance to change data (see Davison, 1988). Furthermore, it is unsurprising that the bias was more pronounced in resistance to change than response rates because resistance to change is determined by stimulus-reinforcer relations established by previous reinforcement contingencies. In contrast, response rates are determined by the present response-reinforcer relations.

The confounding history of the pigeons was unnoticed until after the present experiment. Nevertheless, the current series of conditions allowed us to assess whether relative measures of responding would shift further in favour of Component 2 when 1) removing the brief-stimulus schedule from Component 1 during Condition 2, and 2) when adding the brief-stimulus schedule to Component 2 during Condition 3. These manipulations failed to shift relative response rates or resistance to change further towards Component 2. Therefore, shifting the location of brief stimulus presentations did not overcome the effects of the pre-existing bias.

In sum, the present experiment did not find reliable evidence that brief stimuli have reinforcement-like effects. However, the data were confounded by a pre-existing bias towards the right yellow key. Therefore, we replicated the key procedures in the following experiment with a different set of six pigeons.

3.5   Appendix A3

Figure A3.1. Log proportion of baseline response rates for individual pigeons during each disruption test in Experiment 1 Condition 1. Component 1 (filled data points) arranged an additional schedule of brief stimulus presentations. Columns from left-to-right present data from prefeeding, ICI-food, extinction-with-stimuli, and extinction-without-stimuli tests, respectively.

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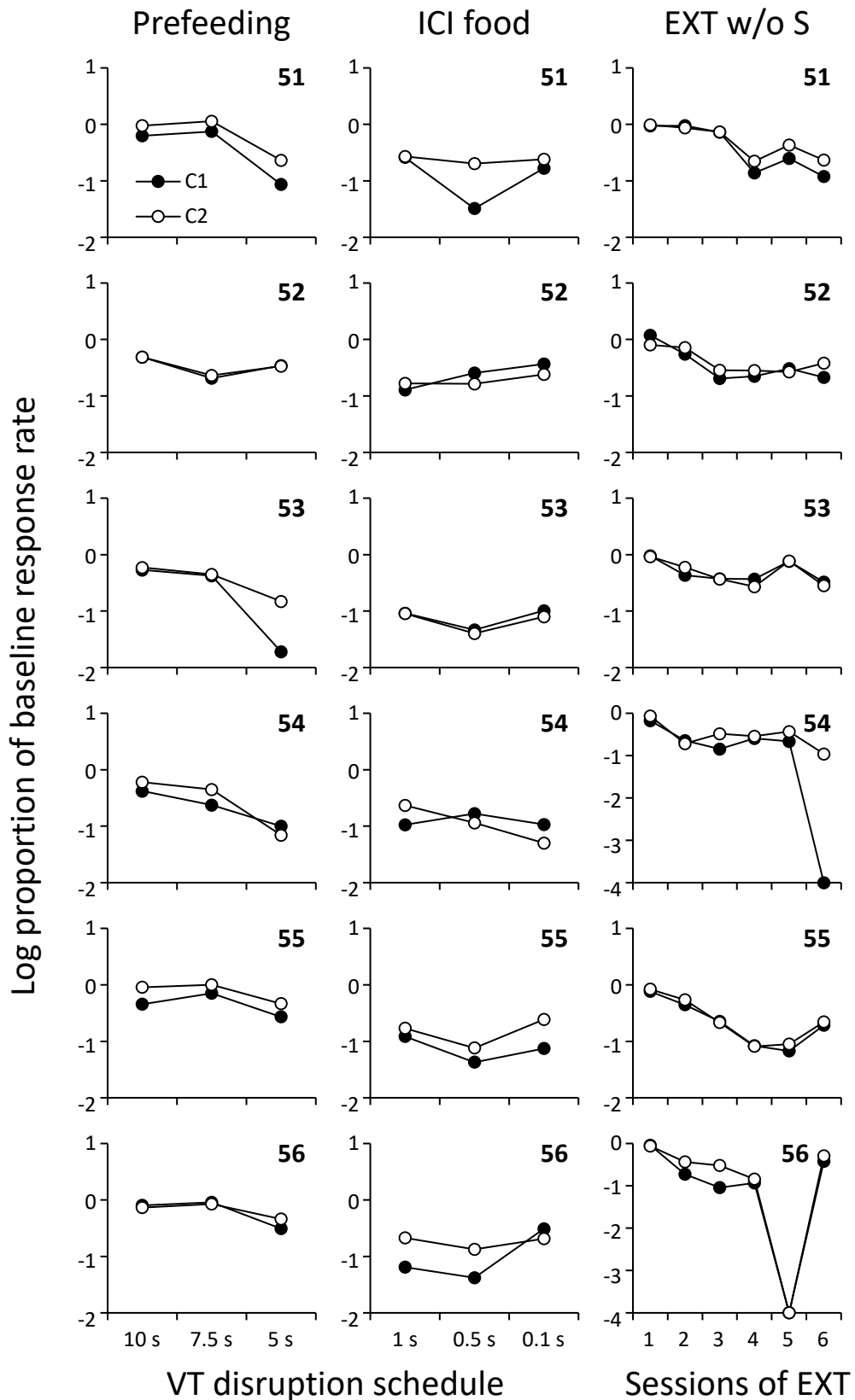
Figure A3.2. Log proportion of baseline response rates for individual pigeons during each disruption test in Experiment 1 Condition 2. Neither component arranged an additional schedule of brief stimulus presentations. Columns from left-to-right present data from prefeeding, ICI-food, and extinction-without-stimuli tests, respectively. Data points representing zero responses are set at -4.
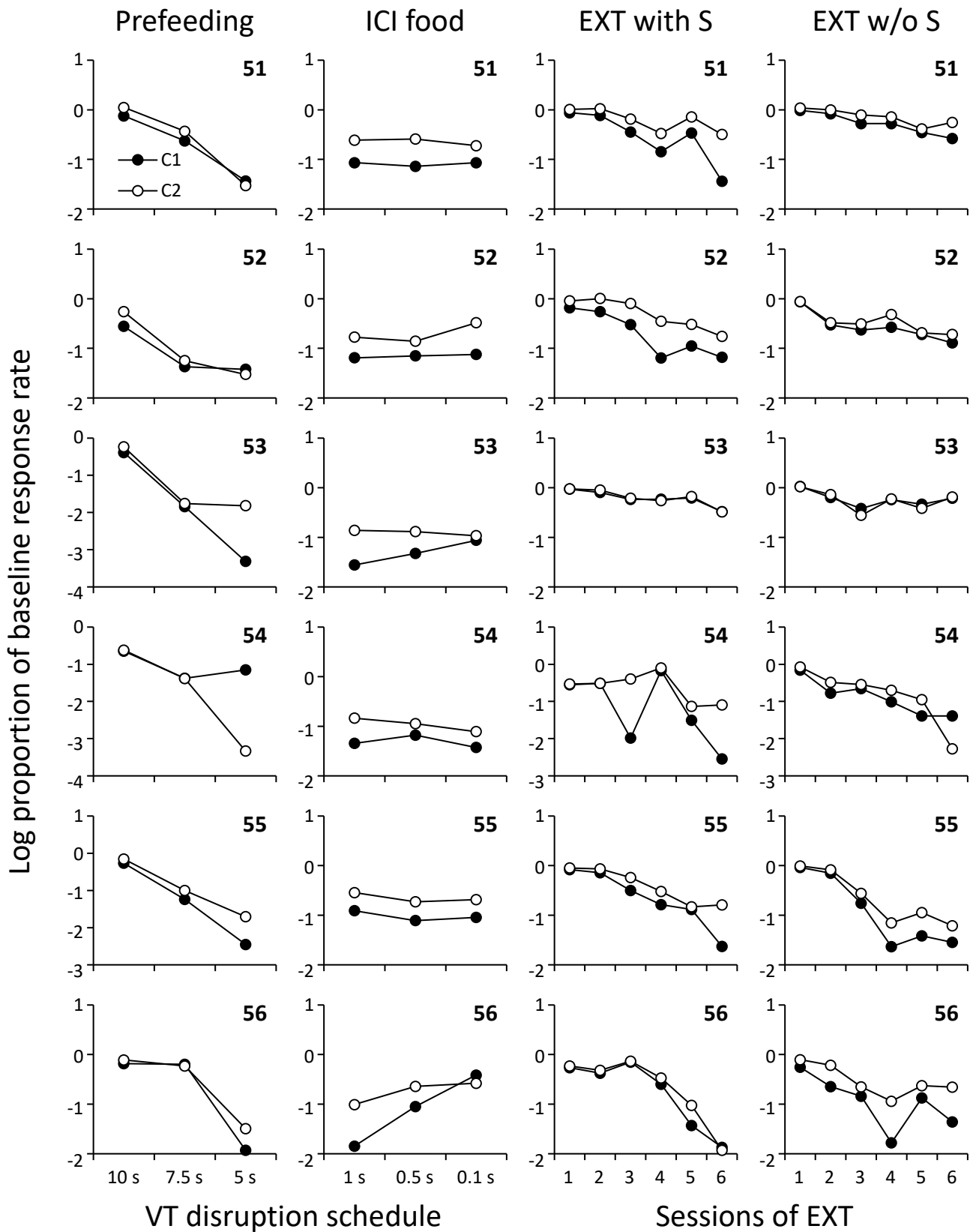
Figure A3.3. Log proportion of baseline response rates for individual pigeons during each disruption test in Experiment 1 Condition 3. Component 2 (unfilled data points) arranged an additional schedule of brief stimulus presentations. Columns from left-to-right present data from prefeeding, ICI-food, extinction-with-stimuli, and extinction-without-stimuli tests, respectively.
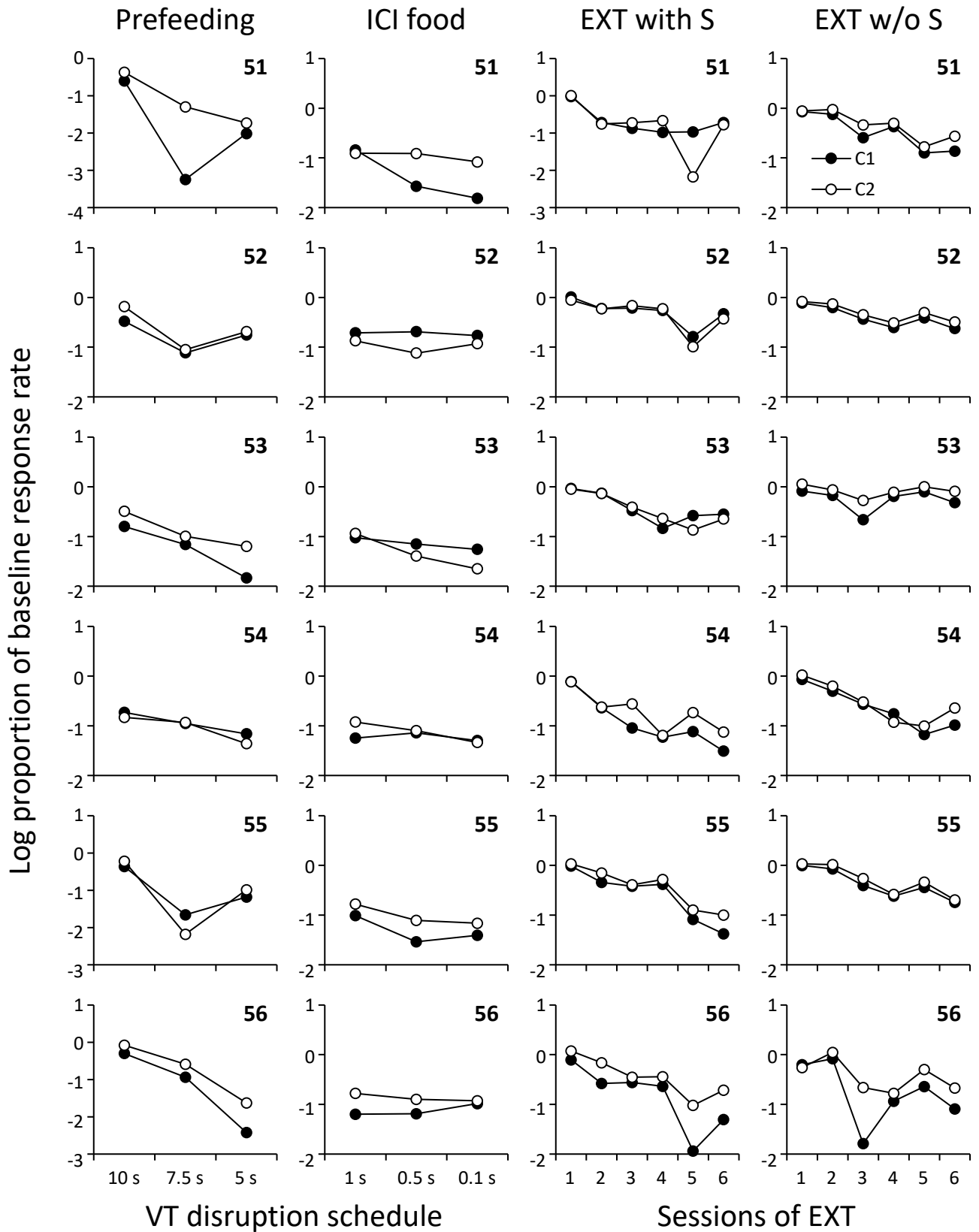
Chapter 4

4.1   Experiment 2

Experiment 1 failed to find reliable reinforcement-like effects of brief stimuli unrelated to food reinforcers. However, the pigeons' responses were consistently biased toward the right yellow key signalling Component 2. This bias potentially confounded the measure of relative resistance to change by potentially competing with any reinforcement-like effect of the brief stimuli. The purpose of Experiment 2 was to replicate the procedures used in Experiment 1 with a separate group of six pigeons. We first assessed the effects of any pre-existing biases on response rates and resistance to change by arranging equal VI 60-s schedules of food reinforcers in both components, without a brief-stimulus schedule in either (Condition 1). Next, we added a VI 60-s schedule of brief stimulus presentations in Component 2 (Condition 2) to replicate the key condition in Experiment 1 and in Podlesnik et al. (2009).

4.2   Method

4.2.1   Subjects

The subjects were 6 pigeons with previous experience in multiple and concurrent schedules. Pigeons were numbered 121 to 126, and maintained at 85% ± 15 g of their free-feeding weights. Housing and deprivation procedures were kept consistent with Experiment 1. Experimental sessions ran 7 days a week at 4 am and no personnel were present during sessions.

4.2.2   Apparatus

The pigeons' home cages also served as experimental chambers. The chambers were similar to those in Experiment 1, and differed only in the number of response keys. Three 20-

mm diameter response keys were mounted in a horizontal row on the right wall, 300 mm above the floor and 70 mm apart, centre to centre. Only the left and right keys were used and both could be transilluminated white, yellow and red. Experimental events were identical to Experiment 1, and were again programmed and recorded by a computer running MED PC® in an adjacent room.

4.2.3   Procedure

The pigeons were experienced before the present study and were introduced directly into the experiment. As with Experiment 1, baseline responses rates were maintained in a two-component multiple schedule arranging equal VI 60-s schedules of food reinforcement in both components. Component 1 was always signalled by the left key lit yellow, and Component 2 was always signalled by the right key lit white. Alternation and timing of components were identical to Experiment 1.

Food and brief stimulus presentations were identical to Experiment 1. Condition 1 arranged food in both components but did not arrange brief stimulus presentations in either component. Condition 2 arranged food in both components and also arranged brief stimulus presentations in Component 2.

Stability of baseline response rates before each disruption test were assessed by visual inspection. Condition 1 and 2 ran 24 and 16 sessions of baseline, respectively, before the first disruption test. A minimum of 13 baseline sessions separated disruption tests within conditions ($M = 17.0$, $SD = 3.1$). The same four disrupter tests from Experiment 1 were used to assess resistance to change: prefeeding, ICI food, extinction with stimuli, and extinction without stimuli.

4.3   Results

Experiment 2 employed the same analyses as in Experiment 1. Table 4.1 presents

mean baseline responses per min and obtained event presentations per hr. In general, obtained

event presentation rates were slightly lower than but nevertheless approximated the scheduled

60 per hr. Appendix Figures A4.1 and to A4.2 present log proportion of baseline responses

rates during each disruptor test in Conditions 1 and 2, as a function of successive VT values

during prefeeding and ICI-food tests, and as a function of successive sessions of extinction

during extinction-with-stimuli and extinction-without-stimuli tests.

Table 4.1

Mean baseline responses per min and obtained food and brief stimulus presentations per hr in
Experiment 2.

Pigeon	Condition	Responses per min		Foods per hr		Stimuli per hr	
		Comp 1	Comp 2	Comp 1	Comp 2	Comp 1	Comp 2
121	1	16.04	25.74	51.67	55.83	-	-
	2	18.22	39.31	52.71	56.04	-	54.58
122	1	83.65	65.63	54.44	56.94	-	-
	2	73.80	55.72	54.79	55.00	-	56.67
123	1	86.33	70.12	56.11	52.78	-	-
	2	80.44	81.89	54.38	54.38	-	55.42
124	1	31.60	38.13	51.39	52.78	-	-
	2	43.30	48.59	53.33	53.96	-	59.17
125	1	27.77	62.99	53.89	54.17	-	-
	2	31.29	72.64	53.33	55.00	-	55.42
126	1	47.03	58.67	54.72	54.17	-	-
	2	45.85	66.17	54.38	54.79	-	56.46

Figure 4.1 shows the relative measures of baseline response rates (left panel) and

resistance to change (right panel) across the two conditions for individual pigeons, as shown

previously in Figure 3.1. Condition 1 did not arrange brief stimuli in either component.

Therefore, we did not run an extinction-with-stimuli test.
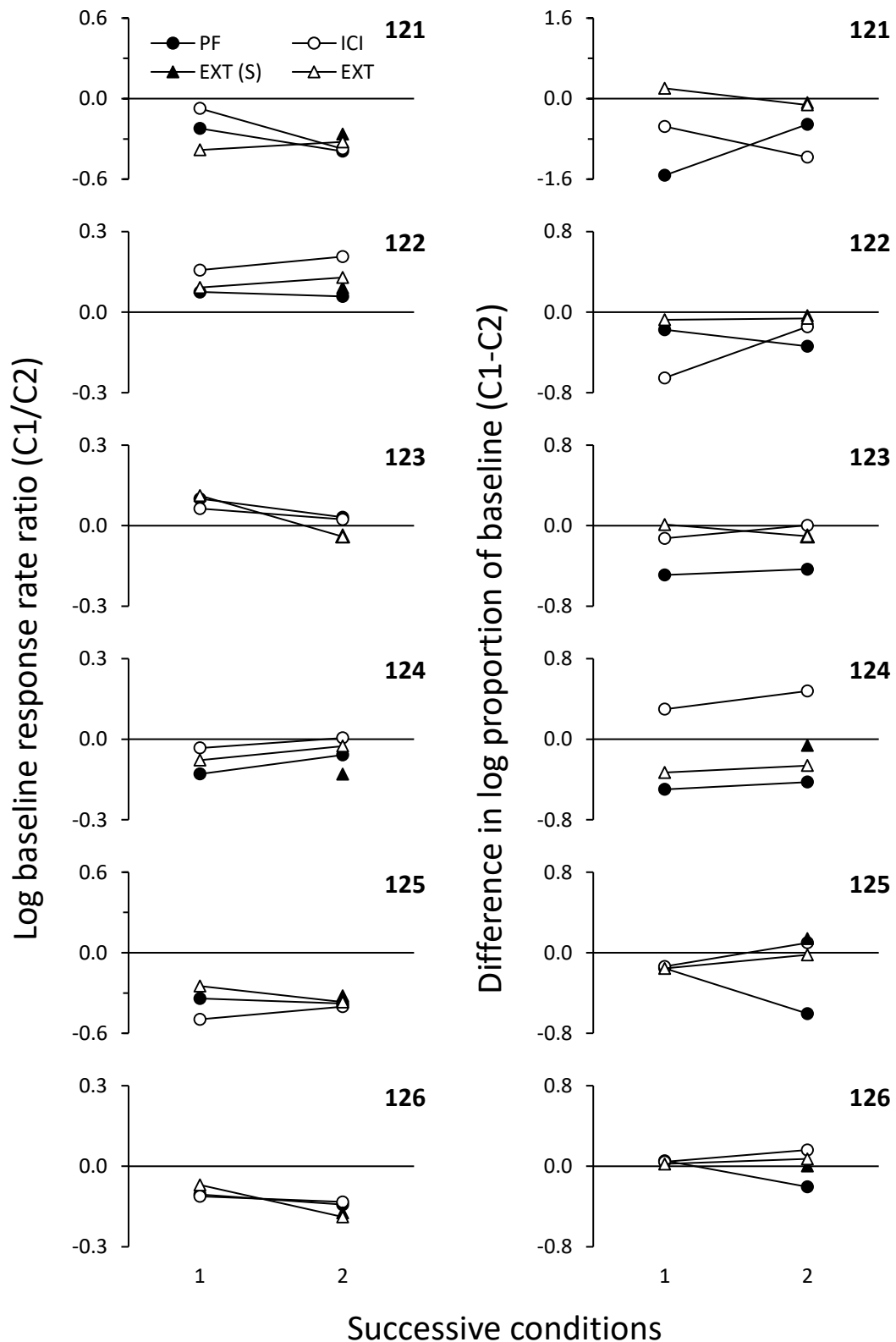
Figure 4.1. Log baseline response rate ratios (left panel) and differences in log proportion of baseline response rates (right panel) across successive conditions for individual pigeons in Experiment 2. Separate functions represent baseline response rates preceding, and resistance to change during, each disrupter test, in the left and right panels, respectively. PF refers to prefeeding, ICI refers to ICI food, EXT(s) refers to extinction with stimuli, and EXT refers to extinction without stimuli.

If the brief stimuli had reinforcement-like effects, data points for Condition 2 should be below the x-axis (set at $y = 0$), and consistently lower (i.e., showing relatively higher Component 2 response rates) than in Condition 1. They were not (Figure 4.1). Four of the six pigeons tended to respond at a higher rate in Component 2 during both Conditions 1 and 2, with the exceptions being 122 and 123. Response rates between components did not change systematically across Conditions 1 and 2.

Relative resistance to change did not differ systematically across components but tended to be greater in Component 2 in both conditions, regardless of whether Component 2 arranged brief stimulus presentations. In Condition 1, 12 of the 18 data points (6 pigeons x 3 disruption tests) were below 0. In Condition 2, 17 of the 24 data points (6 pigeons x 4 disruption tests) were below 0. The exceptions were 123 and 124 in the ICI-food test, 125 in the ICI-food and extinction-with-stimuli tests, and 126 in all but the prefeeding test. Resistance to change was greater in Component 2 across all disruption tests for only two pigeons (121 and 122).

As in Experiment 1, we assessed whether local response rates were higher immediately following the presentation of food versus brief stimulus presentations. Figures 4.2 shows that the median inter-response times (IRTs) after food presentations (unfilled data points) were shorter than pre-food IRTs for all pigeons. However, IRTs after brief stimulus presentations did not differ systematically to pre-stimulus IRTs, with the exception of 121 which had slightly shorter IRTs after brief stimulus presentations. Therefore, local response rates increased reliably after food but not after brief stimulus presentations.
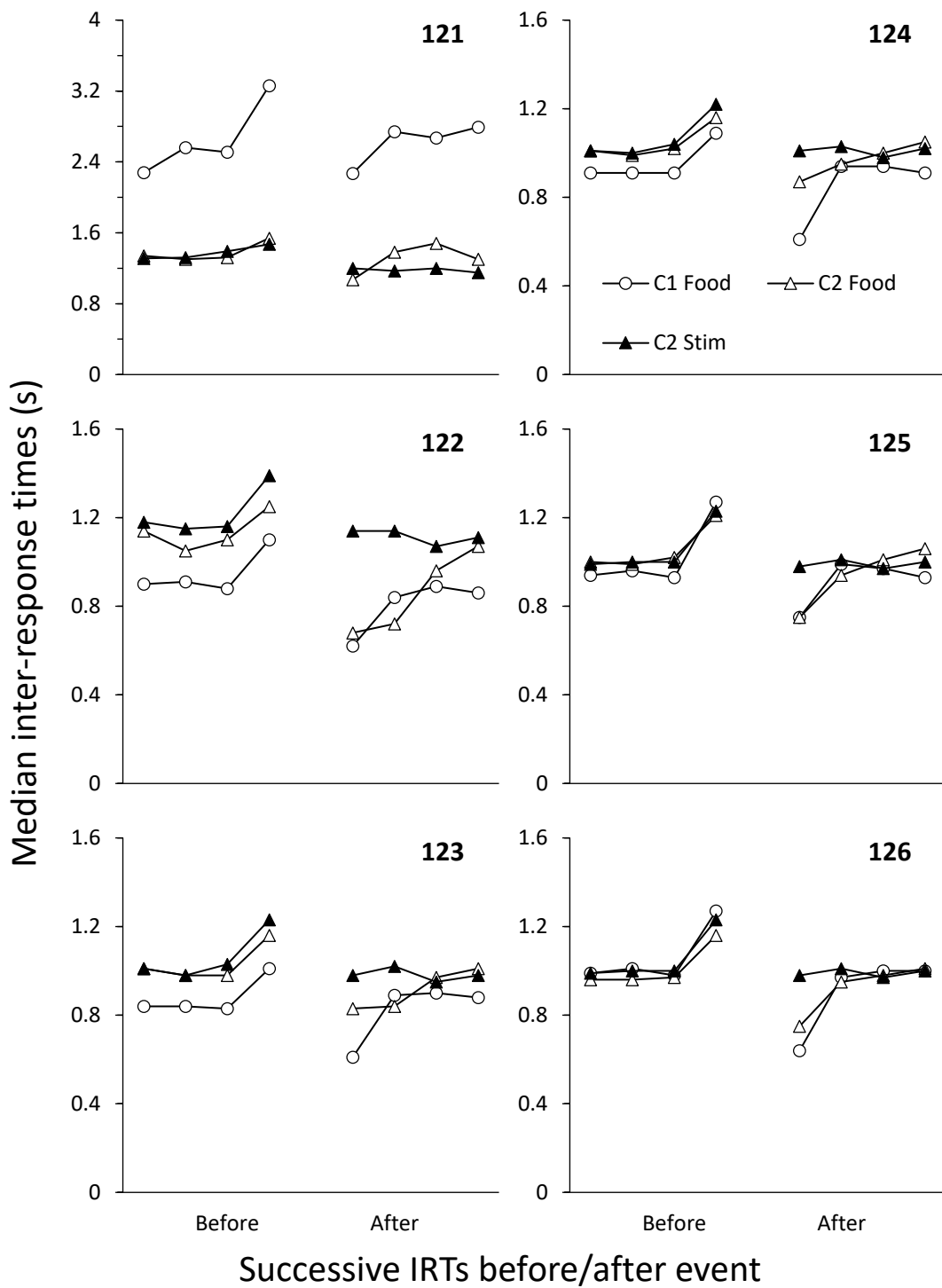
Figure 4.2. Median inter-response times (IRTs) immediately before and after food (unfilled data points) or brief stimulus presentations (filled data points) in Experiment 2 Condition 2.

4.4   Discussion

Consistent with findings from Experiment 1, Experiment 2 failed to produce reliable reinforcement-like effects of brief stimuli unrelated to food reinforcement in a different group of pigeons. Response rates and resistance to change were not systematically greater in a component with versus without an additional schedule of brief stimulus presentations. Neither measure changed systematically when a schedule of brief stimulus presentations was added in Component 2. Furthermore, food presentations increased local response rates but brief stimulus presentations did not. Therefore, we failed to replicate the persistence-enhancing effects of brief stimuli in pigeons reported by Podlesnik et al. (2009).

Despite replicating the programming of brief stimulus presentations used by Podlesnik et al. (2009) in Experiments 1 and 2, there remain a few differences in procedure worth considering. Firstly, the present experiments were conducted in the pigeons' home cages located in a colony room with other pigeons. The room lighting and noise from other experiments being conducted simultaneously might have interfered with discriminating the occurrence of the brief changes in key colour. In contrast, Podlesnik et al. conducted their experiment in separate, lightproof, and sound-attenuating chambers. Secondly, components in Experiment 1 and 2 were always signalled by left and right keys lit yellow and white, or white and yellow, respectively. In contrast, Podlesnik et al. used green, red, and white, and counterbalanced the colours among the components and brief stimulus-presentations across pigeons. Therefore, Experiment 3 sought to address both of these discrepancies to replicate more precisely the conditions of Podlesnik et al.'s study.

4.5   Appendix A4
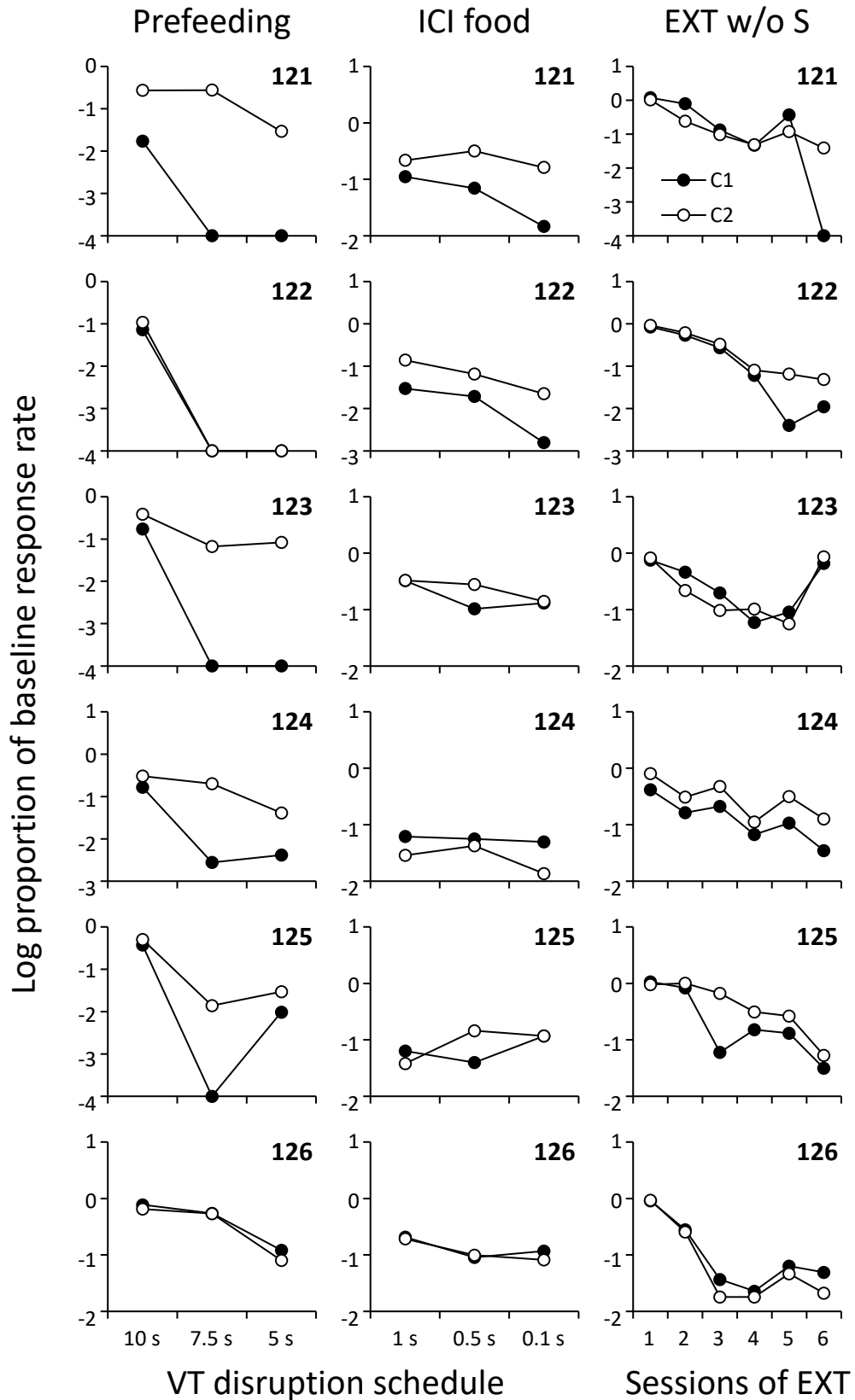
Figure A4.1. Log proportion of baseline response rates for individual pigeons during each disruption test in Experiment 2 Condition 1. Neither component arranged an additional schedule of brief stimulus presentations. Columns from left-to-right present data from prefeeding, ICI-food, and extinction-without-stimuli tests, respectively. Data points representing zero responses are set at -4.

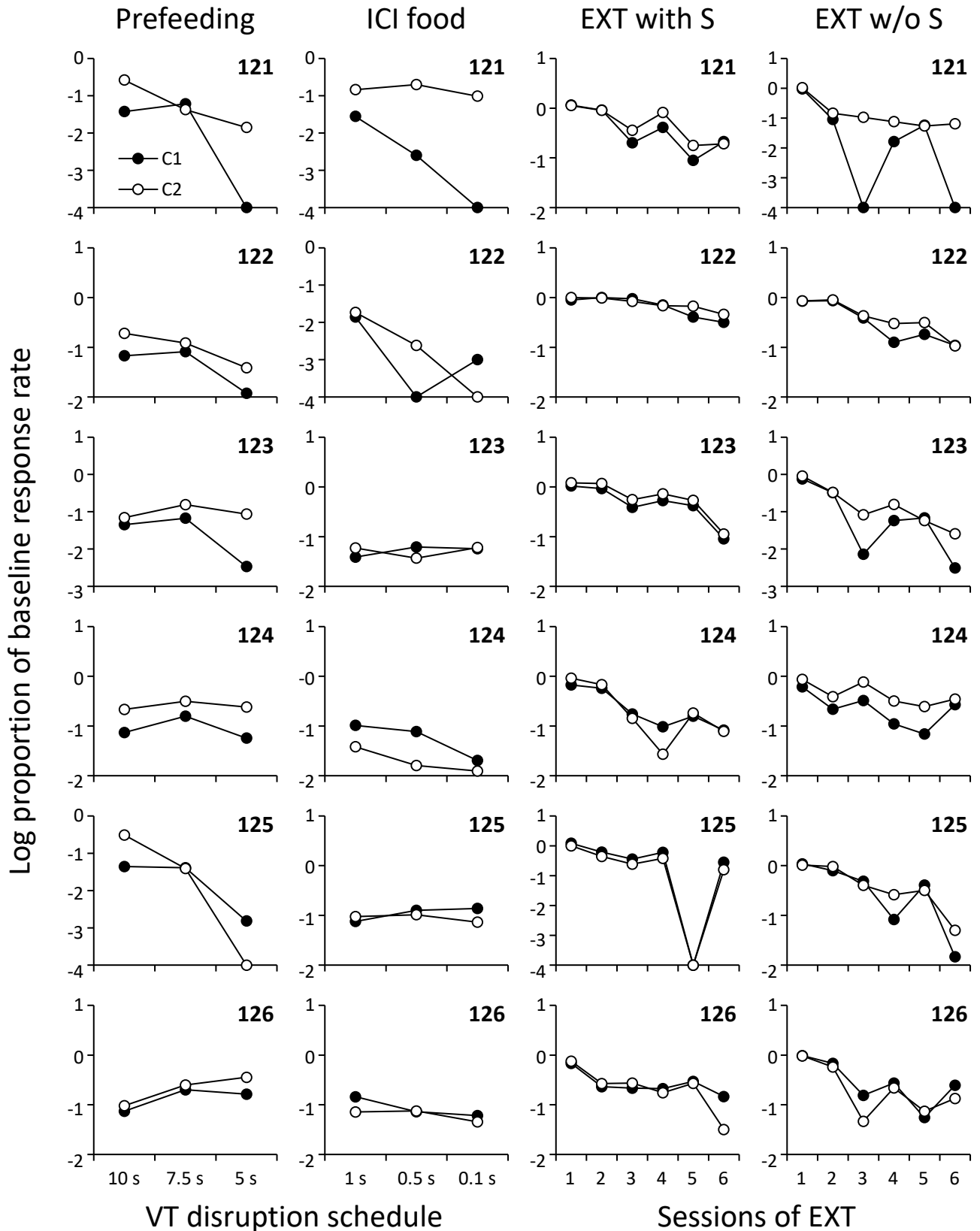Figure A4.2. Log proportion of baseline response rates for individual pigeons during each disruption test in Experiment 2 Condition 2. Component 2 (unfilled data points) arranged an additional schedule of brief stimulus presentations. Columns from left-to-right present data from prefeeding, ICI-food, extinction-with-stimuli, and extinction-without-stimuli tests, respectively. Data points representing zero responses are set at -4.

Chapter 5

5.1   Experiment 3

The purpose of Experiment 3 was to replicate the key condition in Podlesnik et al. (2009) in a more controlled environment. Therefore, we (1) conducted experimental sessions in individual, lightproof, and sound-attenuating chambers and (2) counterbalanced the keylight colours among the discriminative stimuli signalling components and brief stimulus presentations across pigeons, in accordance with Podlesnik et al.'s procedure.

5.2   Method

5.2.1   Subjects

The subjects were 4 pigeons with mixed histories. Pigeons were numbered 441 to 444, and maintained at 85% ± 15 g of their free-feeding weights by post-session supplementary feeding of mixed grain. Pigeons were housed in a separate colony room, with lights turned on at 2 am and off at 6 pm. Water and grit were freely available in their home cages. Experimental sessions were run at 10 am, 7 days a week, in four experimental chambers located in a separate room.

5.2.2   Apparatus

Immediately before sessions, the pigeons were transported from their home cages to four standard Med Associates Inc. experimental chambers located in a separate room. Each chamber was 300 mm high, 320 mm wide, and 240 mm deep, and enclosed in a lightproof and sound-attenuating box containing a ventilation fan. The front and back walls and ceiling were constructed of Plexiglas, and the floor consisted of steel bars. The left and right walls were constructed from metal. Three translucent response keys, measuring 25 mm in diameter, were mounted in a horizontal row on the right wall, 220 mm above the floor and 80 mm apart,

center to center. Only the left and right keys were used and both could be transilluminated green, red, and white. Pecks to a lit key exceeding 0.1 N of force were recorded as responses. A hopper filled with wheat was situated behind a magazine aperture, located 140 mm below the response keys and measuring 50 mm high, 60 mm wide, and 45 mm deep. During reinforcement, the magazine was illuminated, the hopper was raised, and all keys were darkened for 2 s. All experimental events were programmed and recorded by a computer running MED PC® in an adjacent room.

5.2.3   Procedure

The pigeons were experienced before the present study and were introduced directly into the experiment. As with Experiments 1 and 2, baseline responding was established in a two-component multiple schedule, with components signalled by the left and right key lit green, red, or white. Table 5.1 shows that the location and colour associated with each component were counterbalanced across pigeons, as was the colour of brief stimulus presentations. Otherwise, scheduling of components and other events were identical to that of Experiments 1 and 2.

The current experiment ran only a single condition. Food reinforcers were arranged in both components on equal VI 60-s schedules of reinforcement. Brief stimulus presentations were conjointly arranged in Component 1 on an independent VI 60-s schedule, consistent with Experiments 1 and 2. The same four disruption tests used in Experiments 1 and 2 were used in the present experiment. Initially, 31 baseline sessions were run to establish stable baseline response rates before the first disruption test, and a minimum of 15 sessions of baseline separated subsequent disruption tests ($M = 17.0$, $SD = 2.7$). The procedures for each disruption test remained identical to those used in the previous experiments. The order of the two extinction tests (extinction with stimuli and extinction without stimuli) was

counterbalanced across pigeons. The data for Pigeon 444 in the extinction-without-stimuli test

are omitted because the pigeon was ill and did not complete the test.

Table 5.1
Counterbalanced stimuli and response keys in Experiment 3.

| | Component 1 | | Component 2 | | Brief |
Pigeon	Key	Colour	Key	Colour	stimulus
441	Left	Red	Right	White	Green
442	Left	White	Right	Red	Green
443	Right	White	Left	Green	Red
444	Right	Green	Left	White	Red

Note. Brief stimulus presentations were arranged in Component 1 for all subjects.

Table 5.2
Mean baseline responses per min and obtained food and brief stimulus presentations per hr in
Experiment 3.

| | Responses per min | | Foods per hr | | Stimuli per hr | |
Pigeon	Comp 1	Comp 2	Comp 1	Comp 2	Comp 1	Comp 2
441	84.56	74.26	55.00	53.96	53.96	-
442	53.50	58.83	52.29	51.25	50.00	-
443	83.09	55.16	53.54	50.83	52.92	-
444	76.38	52.22	51.25	52.08	51.46	-

5.3   *Results*

We used the same analyses as in Experiments 1 and 2. Table 5.2 shows mean baseline

responses per min and obtained event presentations per hr. In general, obtained event

presentation rates were slightly lower than but nevertheless approximated the scheduled rate

of 60 per hr. Appendix Figures A5.1 presents log proportion of baseline responses rates

during each disruptor test as a function of successive VT values during prefeeding and ICI-

food tests, and as a function of successive sessions of extinction during extinction-with-

stimuli and extinction-without-stimuli tests.

Figure 5.1 shows the relative measures of baseline response rates (left panel) and resistance to change (right panel) for individual pigeons. In both panels, each bar represents a different baseline (left panel) or the results of a different disruption test (right panel).
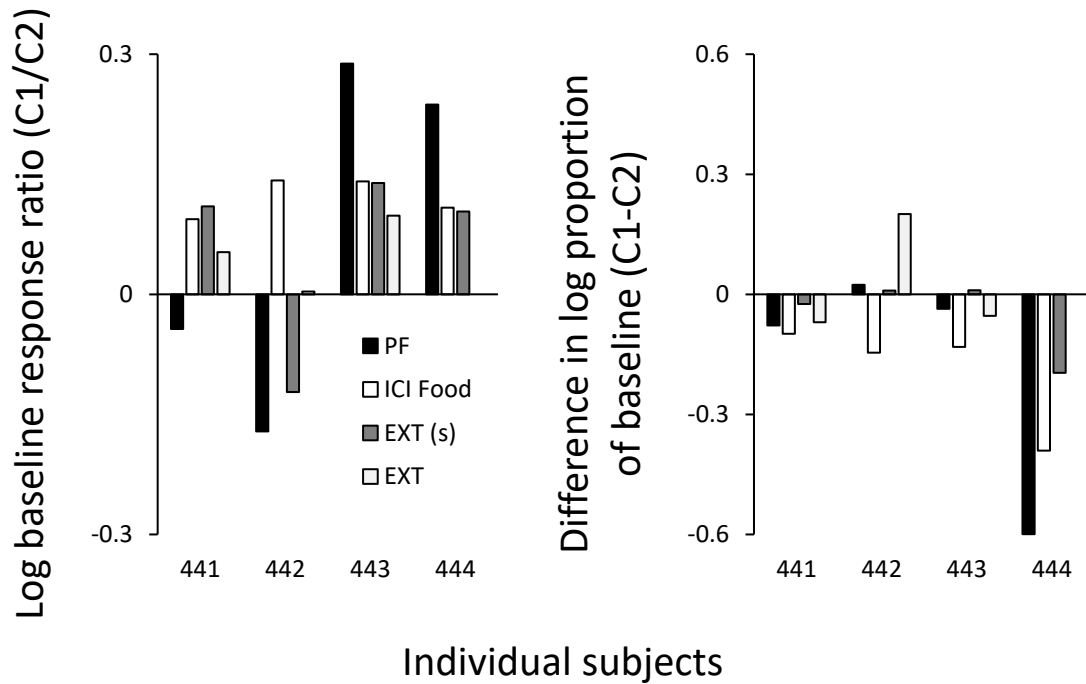
Figure 5.1. Log baseline response rate ratios (left panel) and differences in log proportion of baseline response rates (right panel) for individual pigeons in Experiment 3. Separate bars represent baseline response rates preceding, and resistance to change during, each disrupter test, in the left and right panels, respectively. PF refers to prefeeding, ICI refers to ICI food, EXT(s) refers to extinction with stimuli, and EXT refers to extinction without stimuli.

If brief stimuli have reinforcement-like effects, bars should be above the *x*-axis, in favour of Component 1. Relative response rates during baseline varied across pigeons but tended to be greater in Component 1. Three pigeons (441, 443, and 444) consistently responded at a higher rate in Component 1, with the exception of 441 before the prefeeding test. The other pigeon (442) did not consistently respond at a higher rate in either component.

Relative resistance to change did not differ systematically across components, but tended to be greater in Component 2; 11 of the 15 bars (4 pigeons x 4 disruption tests, minus 444 in the extinction-without-stimuli test) were below 0. However, resistance to change was consistently greater in Component 2 across all disruption tests for only two pigeons (441 and 442), and only slightly so for 441.

A number of raw data files containing within-session event records were lost due to a computer error. Therefore, we did not conduct an IRT analysis on the baseline data from Experiment 3 (cf. Figures 3.2, 3.3, and 4.2).

5.4   Discussion

Consistent with Experiments 1 and 2, Experiment 3 failed to find reliable reinforcement-like effects of brief stimuli in another set of pigeons under experimental conditions more similar to those arranged by Podlesnik et al. (2009). It is perhaps unsurprising that the two modifications in procedure in the present experiment had little effect on the results compared with Experiments 1 and 2. Firstly, it is unlikely that pigeons did not detect the brief stimuli in the previous experiments because the brief stimuli were presented response-contingently on the active key. Therefore, the pigeons were necessarily oriented toward and engaging with the key when the brief stimuli were presented. Secondly, the persistence-enhancing effects of brief stimuli in Podlesnik et al.'s (2009) data were found with counterbalanced stimulus colours. Therefore, it is unlikely that particular colours engendered more or less resistance to change independently from the reinforcement and brief-stimulus contingencies arranged in the presence of the discriminative stimuli.

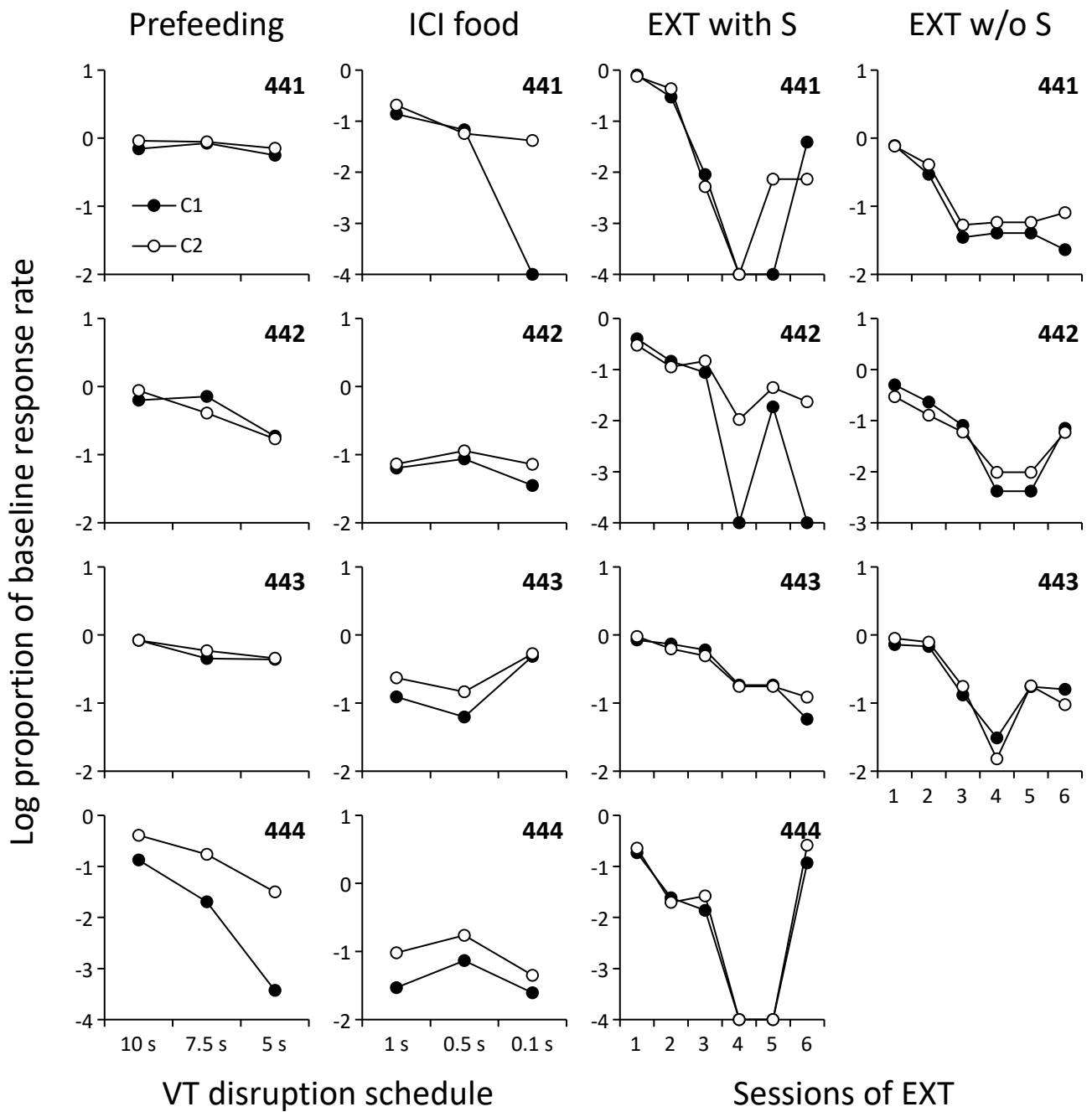Figure A5.1. Log proportion of baseline response rates for individual pigeons during each disruption test in Experiment 3. Component 1 (filled data points) arranged an additional schedule of brief stimulus presentations. Columns from left-to-right present data from prefeeding, ICI-food, extinction-with-stimuli, and extinction-without-stimuli tests, respectively. Data points representing zero responses are set at -4.

Chapter 6

6.1   Experiment 4

The consistent failure to find reinforcement-like effects of brief stimuli unrelated to food reinforcers differs from previously reported findings (Reed & Doughty, 2005; Podlesnik et al., 2009). However, despite using the same parameter values as previous studies, the present experiments have only explored the effects of brief stimuli over a narrow range of parameters. It is possible that reinforcement-like effects are more likely to be detected if, like food reinforcers, brief stimuli were presented at a higher rate or longer duration than assessed in Experiments 1 through 3 (e.g., Nevin 1974; see Nevin & Grace, 2000a, for discussion). Therefore, Experiment 4 examined the effects of a richer schedule and longer duration of brief stimulus presentations. Additionally, we replaced the brief-stimulus schedule with a food schedule in one condition to compare directly the effects of food versus brief stimulus presentations.

6.2   Method

6.2.1   Subjects and Apparatus

Five pigeons used in Experiment 1 served as subjects, with the exception of Pigeon 55, which had died. Housing and deprivation procedures were kept consistent with previous experiments. The experimental chambers were the same as described in Experiment 1.

6.2.2   Procedure

All procedural aspects were identical to the previous experiments except when noted. After the completion of Experiment 1, the locations of the white and yellow keys were reversed to mitigate the existing key bias at the beginning of the present experiment. Each

condition arranged a two-component multiple schedule; Component 1 was signalled by the left key lit yellow, and Component 2 was signalled by the right key lit white.

Table 6.1 summarises the food and the conjoint event scheduling in Component 2 in each condition. Both components arranged food reinforcers according to equal VI 60-s schedules in all conditions. In Condition 1, only the VI 60-s food schedules were active in both components. In the other conditions, Component 2 arranged an additional schedule of brief stimulus or food presentations. Brief stimulus presentations in Conditions 2 and 6 were identical to Experiments 1 and 3. The rate of brief stimulus presentations increased to a VI 15-s schedule in Condition 3, and the duration also increased to 2 s in Condition 4. Food replaced brief stimulus presentations in Condition 5.

Table 6.1
Arranged food schedules in both components, and the conjoint event scheduling in Component 2 in each condition of Experiment 4.

Condition	Food schedule		Added schedule in Comp 2	
	Comp 1	Comp 2	Schedule	Event
1	VI 60 s	VI 60 s	-	-
2	VI 60 s	VI 60 s	VI 60 s	0.5-s Stimulus
3	VI 60 s	VI 60 s	VI 15 s	0.5-s Stimulus
4	VI 60 s	VI 60 s	VI 15 s	2-s Stimulus
5	VI 60 s	VI 60 s	VI 15 s	2-s Food
6	VI 60 s	VI 60 s	VI 60 s	0.5-s Stimulus

In each condition, stable baseline responding was established before disruption tests were introduced separately to assess resistance to change. Stable baseline responding was assessed by visual inspection. A minimum of 13 baseline sessions were arranged before the first disruption test in each condition ($M = 16.7$, $SD = 3.3$), and a minimum of 9 sessions separated disruption tests within each condition ($M = 12.6$, $SD = 3.2$). The same four disrupter tests were used to assess resistance to change: prefeeding, ICI food, extinction with stimuli, and extinction without stimuli. Condition 1 did not arrange brief stimuli in either component,

and Condition 5 arranged an additional schedule of food reinforcers in Component 2.

Therefore we did not run extinction-with-stimuli tests in Conditions 1 and 5.

6.3   Results

The present experiment used the same analyses as previous experiments. Table 6.2

shows mean baseline responses per min and obtained event presentations per hr. In general,

obtained event presentation rates were slightly lower than but nevertheless approximated the

scheduled rates across conditions. Appendix Figures A6.1 to A6.6 present log proportion of

baseline responses rates during each disruptor test in Conditions 1 through 6 as a function of

successive VT values during prefeeding and ICI-food tests, and as a function of successive

sessions of extinction during extinction-with-stimuli and extinction-without-stimuli tests.

Figures 6.1 and 6.2 shows the relative measures of baseline response rates and

resistance to change, respectively, across successive conditions for individual pigeons. If any

events added to Component 2 have reinforcement-like effects, data points in Figures 6.1 and

6.2 should be below the *x*-axis (set at $y = 0$), and consistently lower than in Condition 1, in

conditions arranging additional event presentations in Component 2 (i.e., Conditions 2

through 6).

Across conditions and pigeons, Figure 6.1 showed no systematic effect of adding brief

stimuli or food to Component 2. Condition 3 suggests that increasing the rate of brief stimulus

presentations might have increased response rates in Component 2 for 52 and 56, but these

effects were not general across pigeons. Only 54 showed a reliable effect of adding food

presentations to Component 2.

Table 6.2
Mean baseline responses per min and obtained food and brief stimulus presentations per hr in Experiment 4.

Pigeon	Condition	Responses per min		Foods per hr		Stimuli per hr	
		Comp 1	Comp 2	Comp 1	Comp 2	Comp 1	Comp 2
51	1	56.63	60.19	54.72	57.22	-	-
	2	63.08	66.94	55.42	55.00	-	58.13
	3	61.52	70.51	55.00	54.79	-	231.88
	4	59.52	80.66	55.00	55.00	-	231.88
	5	69.06	103.24	53.89	53.61	-	230.00[a]
	6	61.39	85.23	53.33	55.42	-	57.71
52	1	61.25	56.13	56.94	56.39	-	-
	2	61.98	52.81	53.75	54.58	-	57.08
	3	60.15	69.69	55.21	54.38	-	227.71
	4	56.62	70.89	54.17	55.83	-	227.29
	5	53.26	77.83	53.89	55.83	-	231.94[a]
	6	54.21	65.53	55.42	55.00	-	57.08
53	1	80.61	80.90	53.33	53.89	-	-
	2	76.81	80.51	55.63	55.83	-	56.67
	3	84.64	85.15	54.79	53.75	-	234.17
	4	83.26	86.95	54.58	54.17	-	232.29
	5	85.19	105.32	58.06	57.22	-	232.22[a]
	6	79.74	87.53	57.08	54.79	-	57.50
54	1	81.16	114.83	54.72	54.72	-	-
	2	79.10	88.58	55.83	56.25	-	59.38
	3	89.43	99.99	55.42	55.00	-	228.75
	4	77.13	97.40	54.17	51.04	-	221.88
	5	44.26	139.64	51.94	56.39	-	234.17[a]
	6	76.97	87.79	55.63	55.83	-	56.88
56	1	54.09	59.19	55.56	56.11	-	-
	2	50.72	54.90	53.75	53.54	-	56.88
	3	43.23	63.85	52.29	54.79	-	228.33
	4	54.77	65.69	55.63	54.79	-	226.67
	5	61.06	76.44	55.28	55.00	-	228.89[a]
	6	54.71	61.77	53.75	55.21	-	60.00

[a] The added schedule in Condition 5 arranged food presentations instead of brief stimulus presentations.
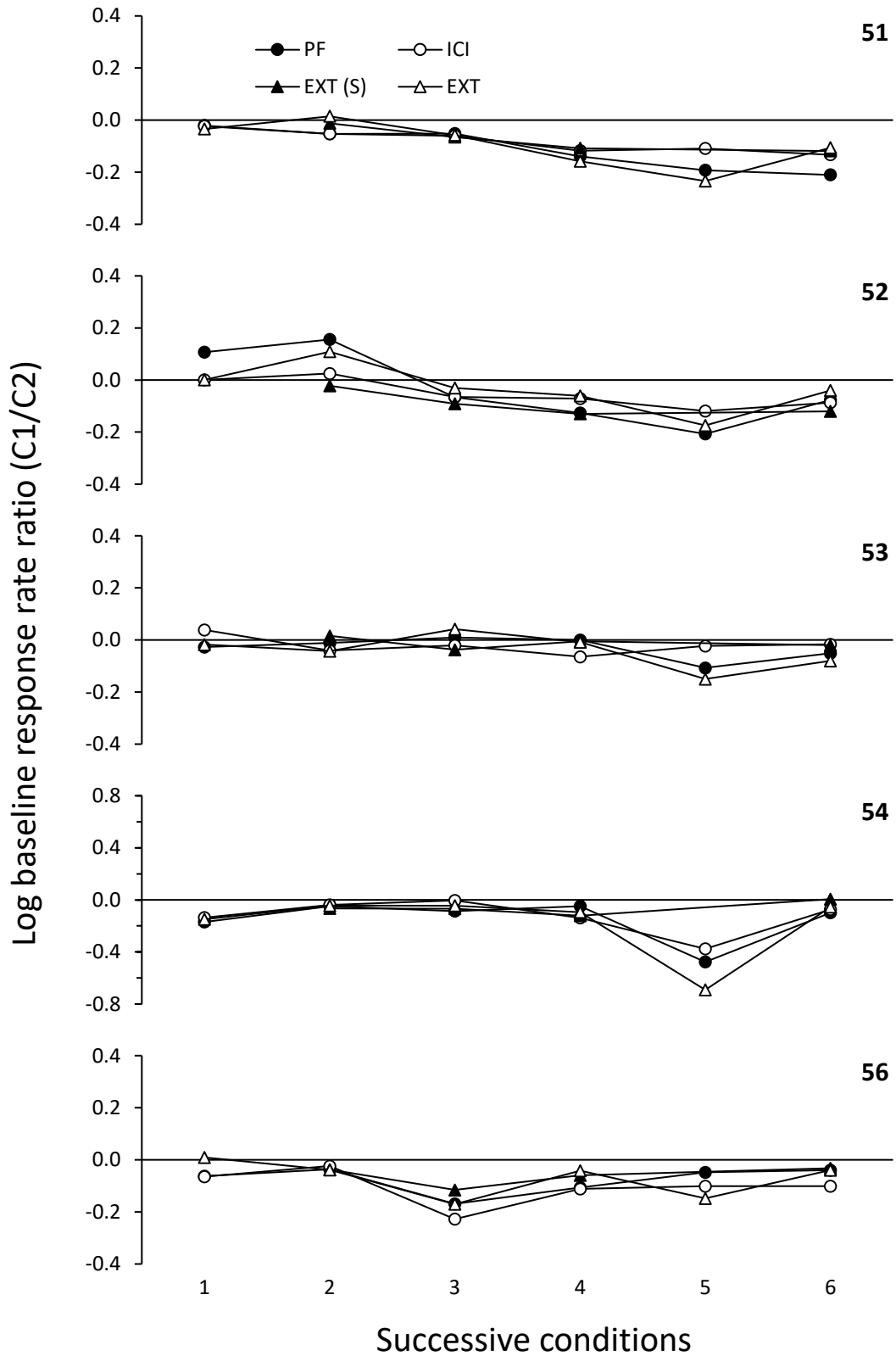
Figure 6.1. Log baseline response rate ratios across successive conditions for individual pigeons in Experiment 4. Separate functions represent baseline response rates preceding each disrupter test. PF refers to prefeeding, ICI refers to ICI food, EXT(s) refers to extinction with stimuli, and EXT refers to extinction without stimuli.
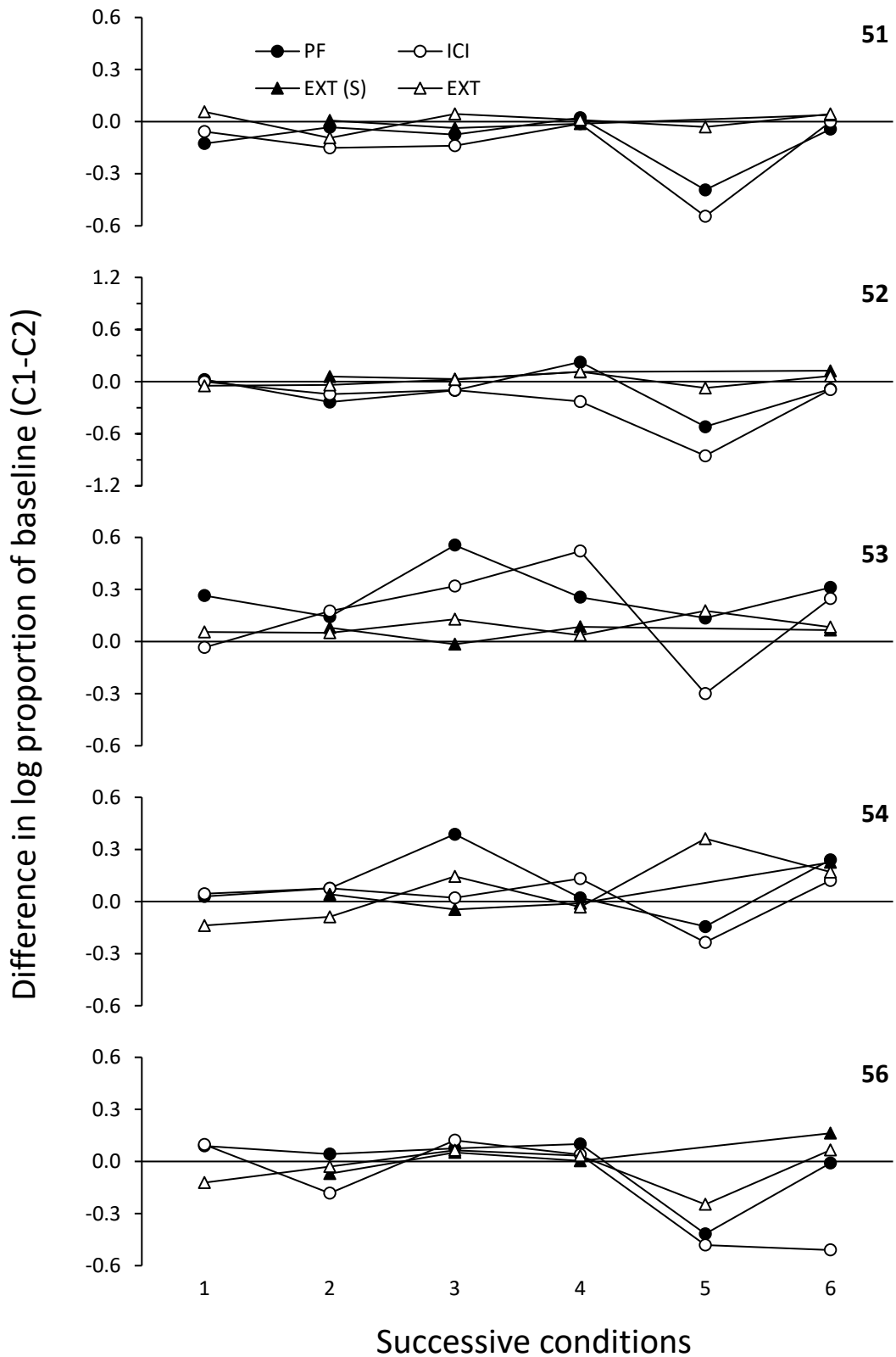
Figure 6.2. Differences in log proportion of baseline response rates across successive conditions for individual pigeons in Experiment 4. Separate functions represent resistance to change during each disrupter test. PF refers to prefeeding, ICI refers to ICI food, EXT(s) refers to extinction with stimuli, and EXT refers to extinction without stimuli.

Figure 6.2 shows relative resistance to change between components. In Condition 1, 7 of the 15 data points (5 pigeons x 3 disruption tests) were below 0. Therefore, there appeared to be no systematic biases in resistance to change to either component at the beginning of the experiment (cf. Experiment 1). In the remainder of the conditions, relative resistance to change did not differ systematically between components or across conditions, with the exception of Condition 5, which arranged an additional schedule of food presentations in Component 2. In Condition 5, resistance to change was systematically greater in Component 2 than Component 1, with 12 of the 15 data points being below 0. The exceptions were 53 in the prefeeding and extinction tests, and 54 in the extinction test. Relative resistance to change decreased in favour of Component 2 between Conditions 4 and 5 for 13 of the 15 tests, with the exceptions being 53 and 54 in the extinction-without-stimuli test. Furthermore, relative resistance to change increased in favour of Component 1 between Conditions 5 and 6 for 12 of the 15 tests, with the exceptions being 53 and 54 in the extinction-without-stimuli test, and 56 in the ICI-food test.

6.4   Discussion

Experiment 4 failed to find reliable reinforcement-like effects of brief stimuli unrelated to food reinforcement, despite increasing the rate and duration of the brief stimulus presentations. Resistance to change was systematically greater in Component 2 only when an added food schedule was arranged. These results replicate and extend the findings of Experiments 1 through 3 showing no reliable reinforcement-like effects of brief stimulus presentations, and are contrary to the findings of Podlesnik et al. (2009).

Increasing the rate and duration of brief stimulus presentations across conditions did not have any apparent effects on response rates or resistance to change. This result differs from the effects of food reinforcement, which generally increase both response rates and

resistance to change when presented at higher rates or greater magnitudes between components of a multiple schedule (e.g., Nevin, 1974; see Nevin & Grace, 2000a). This result also differs from Podlesnik et al.'s (2009) Experiment 2, which found *lower* resistance to change with a higher rate of brief stimulus presentations (VI 15-s schedule) when compared with a lower rate of brief stimulus presentations (VI 60-s schedule). However, this difference was only apparent when assessed within subjects and conditions, between components of a multiple schedule. In their Experiment 1, Podlesnik et al. found no difference between high and low rates of brief stimuli when assessed across groups of pigeons – both increased resistance to change compared with no added brief stimuli. In contrast, the present experiment compared the effects of different rates of brief stimuli within the same pigeons but across different conditions and found no systematic effects of brief stimuli. Consistent with previous research (e.g., Shull & Grimes, 2006; Podlesnik et al., 2016), differences in resistance to change appear more consistent when compared within subjects and conditions than between subjects or conditions.

The present data support Experiments 1 through 4. There were no systematic effects of adding brief stimuli on response rates or resistance to change, regardless of whether the brief stimuli increased in rate or duration. One explanation for the lack of effect of the brief stimuli is that resistance to change is not sensitive enough to be impacted by adding brief stimuli to the discriminative stimulus. Lack of sensitivity is especially a problem if the effects of added brief stimuli are small relative to the effects of added food. Therefore, examining the effects of brief stimuli using more sensitive measures might detect reinforcement-like effects of brief stimuli. This was the goal of the next and final experiment.
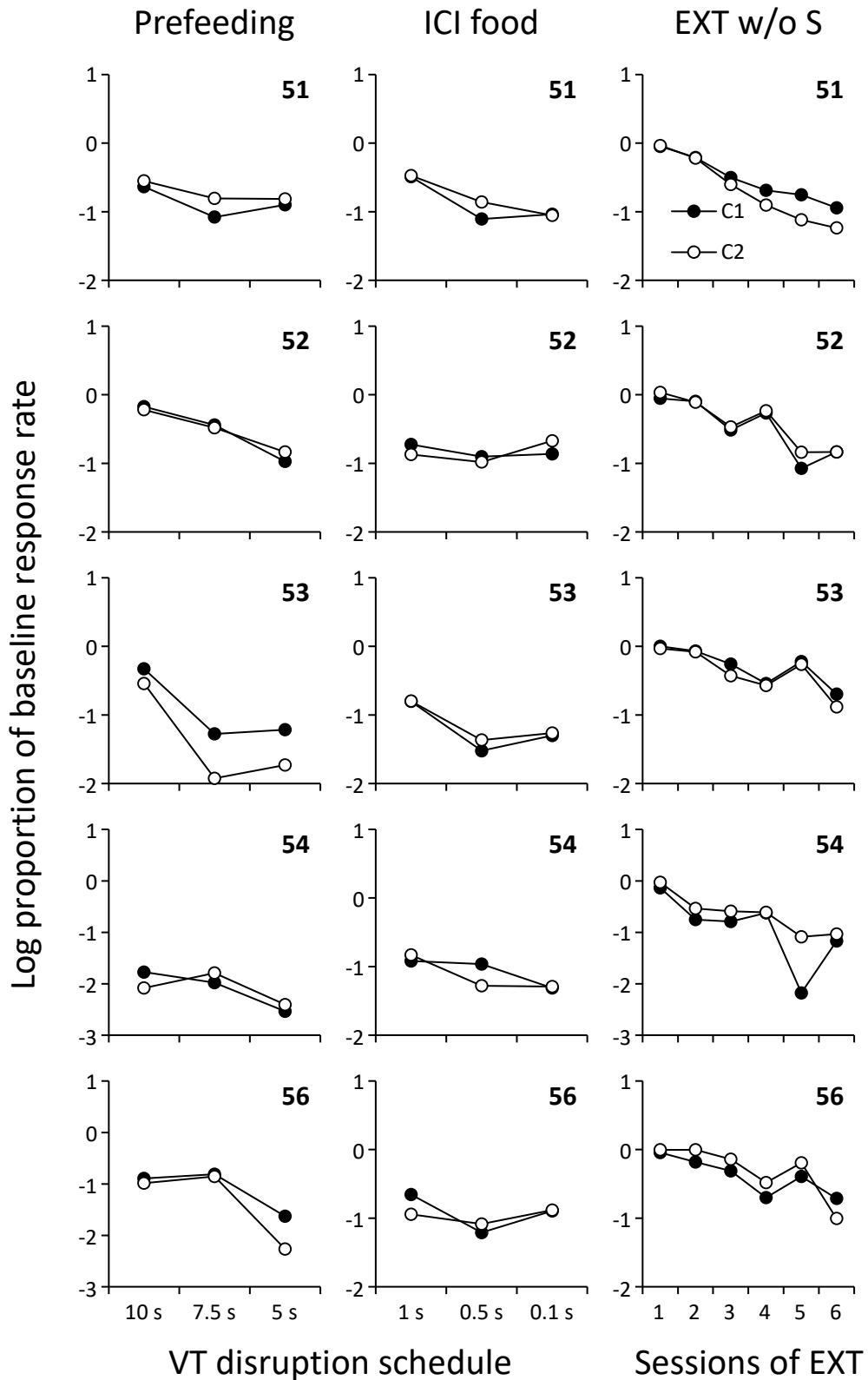
Figure A6.1. Log proportion of baseline response rates for individual pigeons during each disruption test in Experiment 4 Condition 1. Neither component arranged an additional schedule of brief stimulus presentations. Columns from left-to-right present data from prefeeding, ICI-food, and extinction-without-stimuli tests, respectively.

Figure A6.2. Log proportion of baseline response rates for individual pigeons during each disruption test in Experiment 4 Condition 2. Component 2 (unfilled data points) arranged an additional VI 60-s schedule of 0.5-s brief stimulus presentations. Columns from left-to-right present data from prefeeding, ICI-food, extinction-with-stimuli, and extinction-without-stimuli tests, respectively. Data points representing zero responses are set at -4.
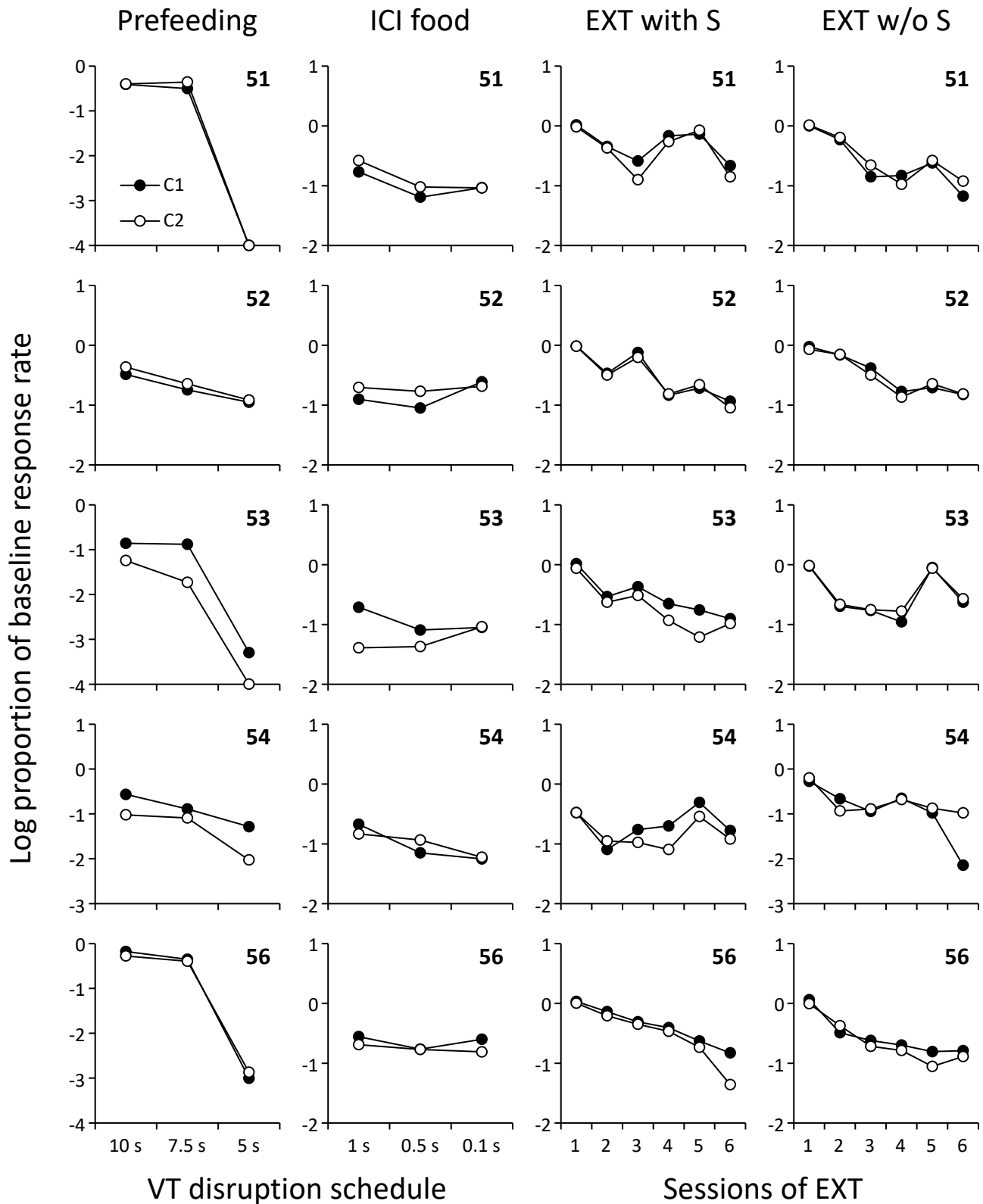
Figure A6.3. Log proportion of baseline response rates for individual pigeons during each disruption test in Experiment 4 Condition 3. Component 2 (unfilled data points) arranged an additional VI 15-s schedule of 0.5-s brief stimulus presentations. Columns from left-to-right present data from prefeeding, ICI-food, extinction-with-stimuli, and extinction-without-stimuli tests, respectively. Data points representing zero responses are set at -4.
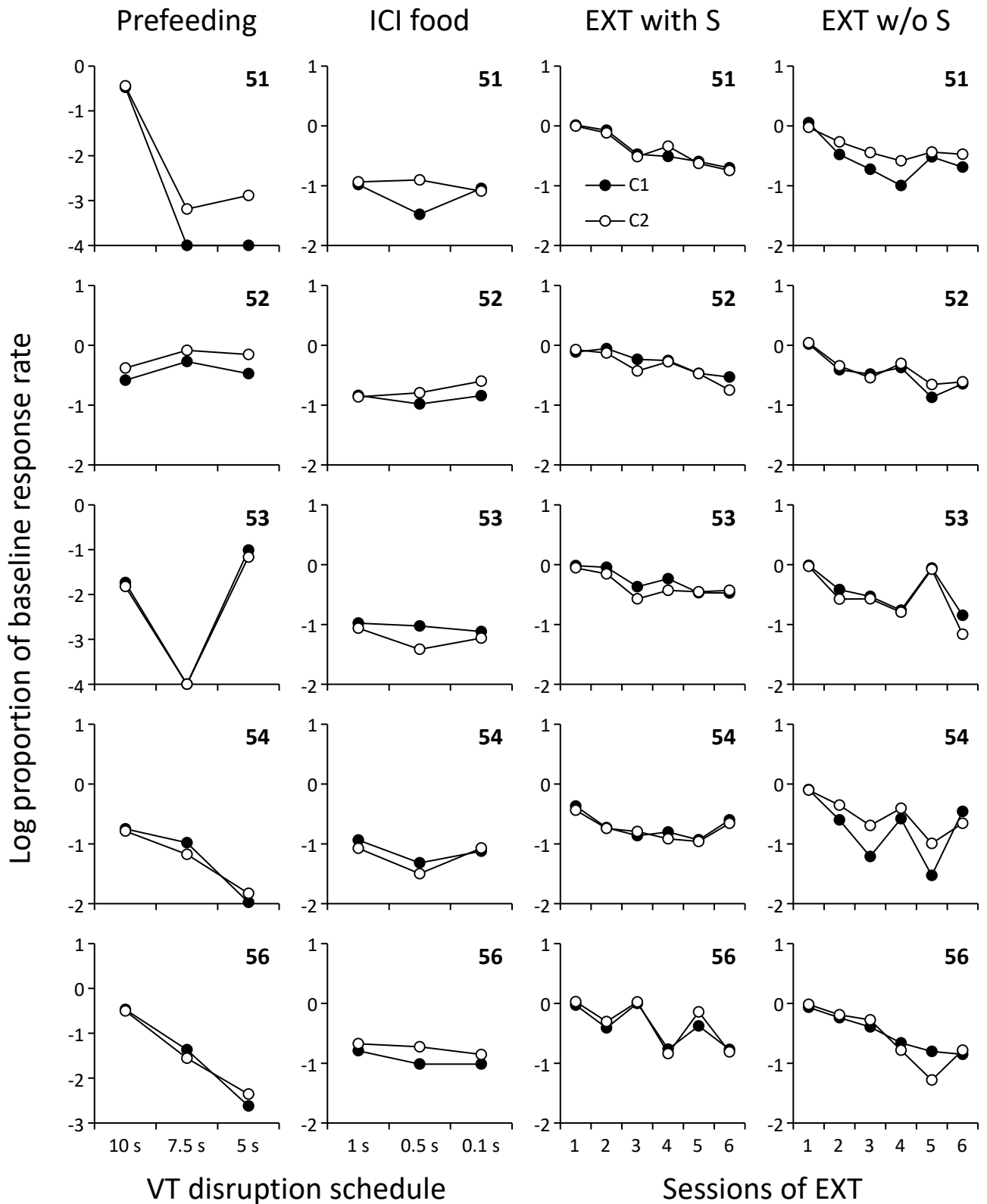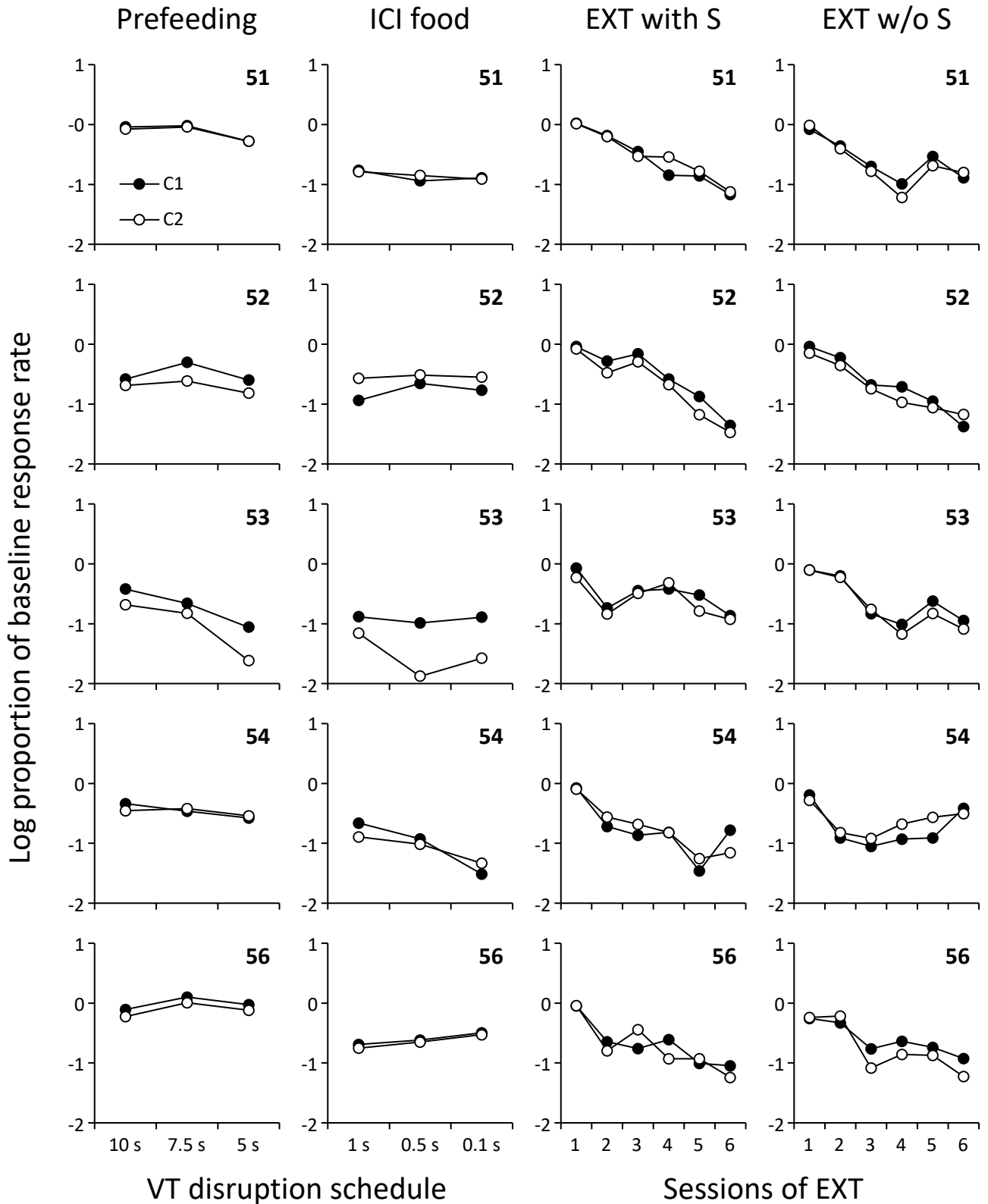
Figure A6.4. Log proportion of baseline response rates for individual pigeons during each disruption test in Experiment 4 Condition 4. Component 2 (unfilled data points) arranged an additional VI 15-s schedule of 2-s brief stimulus presentations. Columns from left-to-right present data from prefeeding, ICI-food, extinction-with-stimuli, and extinction-without-stimuli tests, respectively.
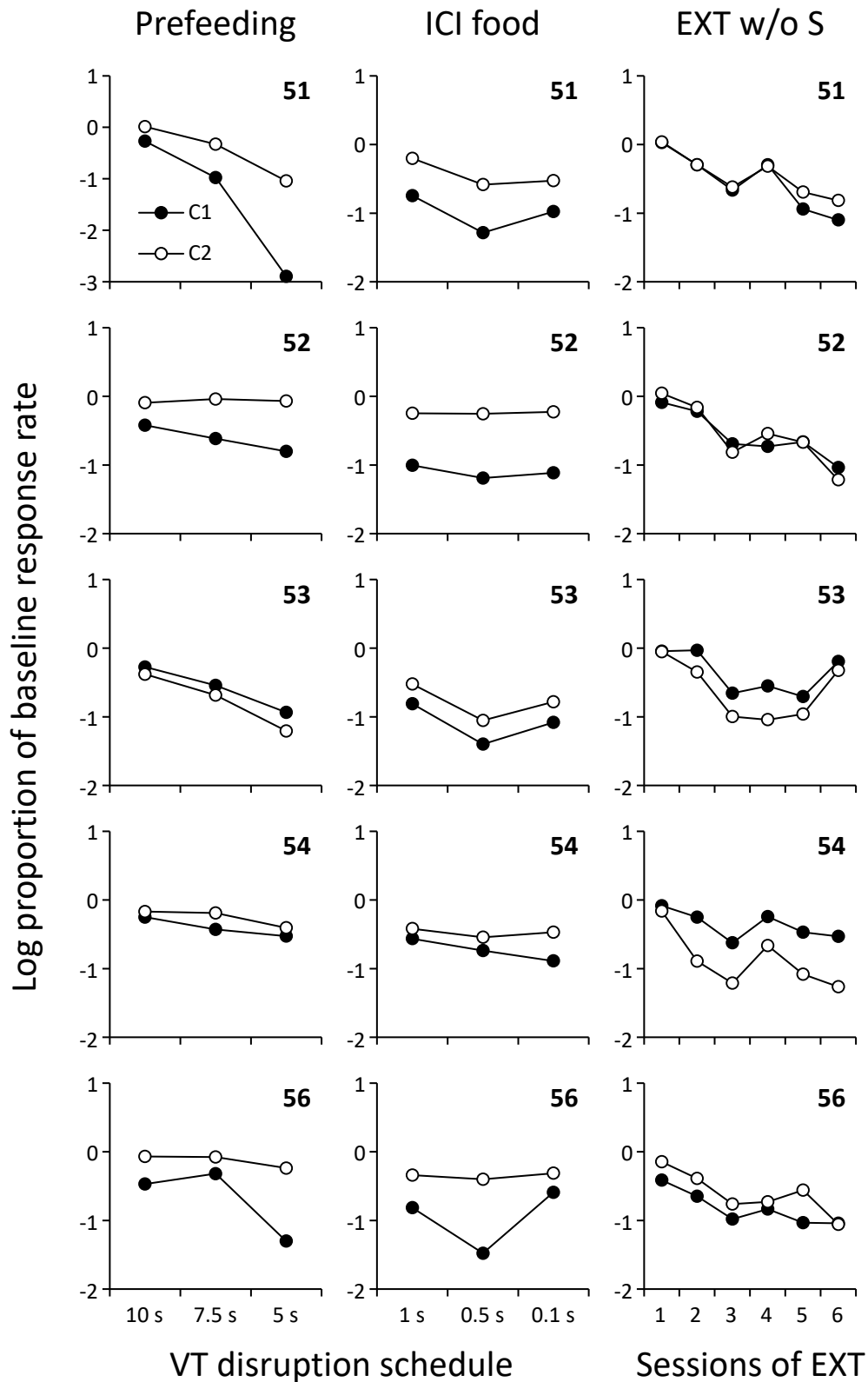
Figure A6.5. Log proportion of baseline response rates for individual pigeons during each disruption test in Experiment 4 Condition 5. Component 2 (unfilled data points) arranged an additional VI 15-s schedule of food. Columns from left-to-right present data from prefeeding, ICI-food, and extinction-without-stimuli tests, respectively.
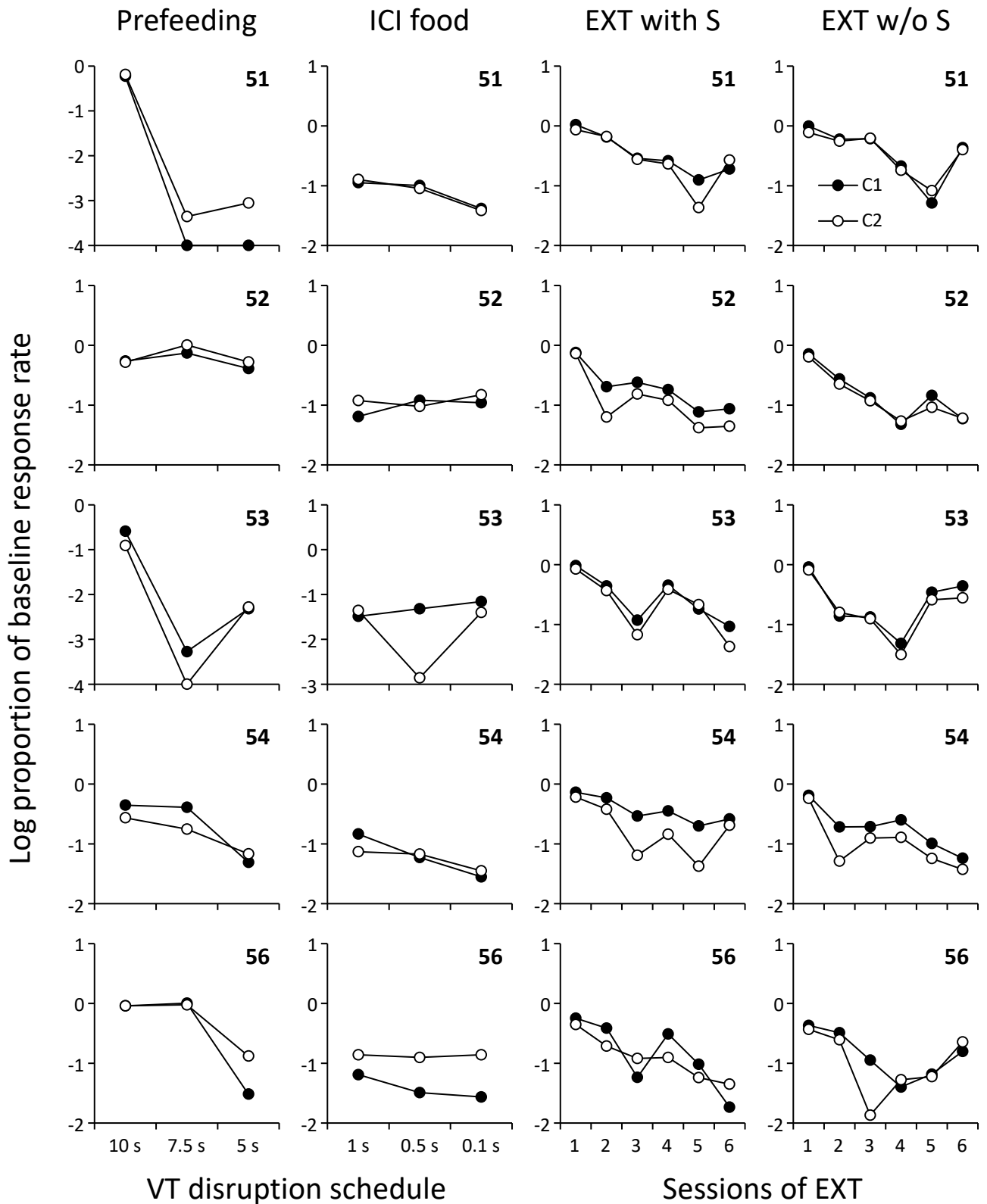
Figure A6.6. Log proportion of baseline response rates for individual pigeons during each disruption test in Experiment 4 Condition 6. Component 2 (unfilled data points) arranged an additional VI 60-s schedule of 0.5-s brief stimulus presentations. Columns from left-to-right present data from prefeeding, ICI-food, extinction-with-stimuli, and extinction-without-stimuli tests, respectively. Data points representing zero responses are set at -4.

Chapter 7

7.1   Experiment 5

Experiments 1 through 4 replicated the multiple-schedule procedure used by Reed and

Doughty (2005) and Podlesnik et al. (2009), but failed to find reliable reinforcement-like

effects of brief stimuli unrelated to food. These procedures assessed the effects of brief stimuli

using relative baseline response rates and resistance to change across components of a

multiple schedule. It is possible that brief stimulus presentations do have some small

reinforcement-like effects, but these measures were not sensitive enough to detect any such

effects.

An alternative measure demonstrated to provide a more sensitive index of

reinforcement-like effects is choice between concurrently available alternatives (i.e.,

preference). Indeed, a large literature shows that relative response rates across different

reinforcement schedules are more sensitive to differences in reinforcer rates when the

alternatives are available concurrently, than when available successively across components

in multiple schedules (e.g., Lobb & Davison, 1977; see Davison & McCarthy, 1988;

McSweeney et al., 1986, for reviews). Preference between discriminative stimuli signalling

different reinforcement rates has also been found to be more sensitive to differences in rates

of primary reinforcement than relative resistance to change within discriminative stimuli

(Grace & Nevin, 1997; 2000; Nevin & Grace, 2000b). Therefore, preference between

discriminative stimuli likely is a superior measure for assessing the effects of brief stimuli

over relative response rates or resistance to change. Furthermore, studies from the framework

of behavioral momentum theory show that preference and resistance to change are correlated

and suggest these are converging measures of the common underlying construct of response

strength, or stimulus value (see Nevin & Grace, 2000a). Therefore, the present experiment

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used a concurrent-chains procedure (see e.g., Autor, 1969) to assess whether pigeons would prefer a component with versus without additional brief stimulus presentations. Additionally, we replaced brief stimulus presentations with food in some conditions to assess the different effects of the two events (see also Experiment 4).

7.2   Method

7.2.1   Subjects and Apparatus

Subjects were the same 5 pigeons (51, 52, 53, 54, and 56) as in Experiments 1 and 4. Housing and deprivation procedures were kept identical to the previous experiments, and the experimental chambers were the same as those used in Experiments 1 and 4.

7.2.2   Procedure

The pigeons were introduced to the present experiment directly after completion of Experiment 4. Each condition arranged a concurrent-chains procedure with parameters that matched those used in the multiple schedules in previous experiments. Figure 1.1 diagrams the concurrent-chains procedure, and is re-presented here as Figure 7.1 for convenience. In the initial link, the left and right keys were lit yellow and white, respectively, and flashed on/off every 0.5 s. Access to the terminal links was arranged dependently according to a single VI 30-s schedule, sampling from 13 intervals (Flesher & Hoffman, 1962), and the next-available terminal link was selected pseudo-randomly from a list (see Grace & Nevin, 1997; Schwartz, 1969, for similar programming). This arrangement equalised exposure to the two terminal links so that each session consisted of 12 presentations of each terminal link. A VI 30-s schedule was used to correspond to the 30-s ICI used in the previous multiple-schedule experiments. Consistent with previous research, the VI timer started only after the first response to either key (e.g., Grace & Nevin, 1997; Jimenez-Gomez & Shahan, 2012; Nevin &

Grace, 2000b; Podlesnik, Jimenez-Gomez, Thrailkill, & Shahan, 2011). No changeover delay was programmed (cf. Herrnstein, 1961).

Initial Link

Alt. 1   Alt. 2

0.5-s   0.5-s
on/off   on/off

On   On

Terminal Link 1   Terminal Link 2
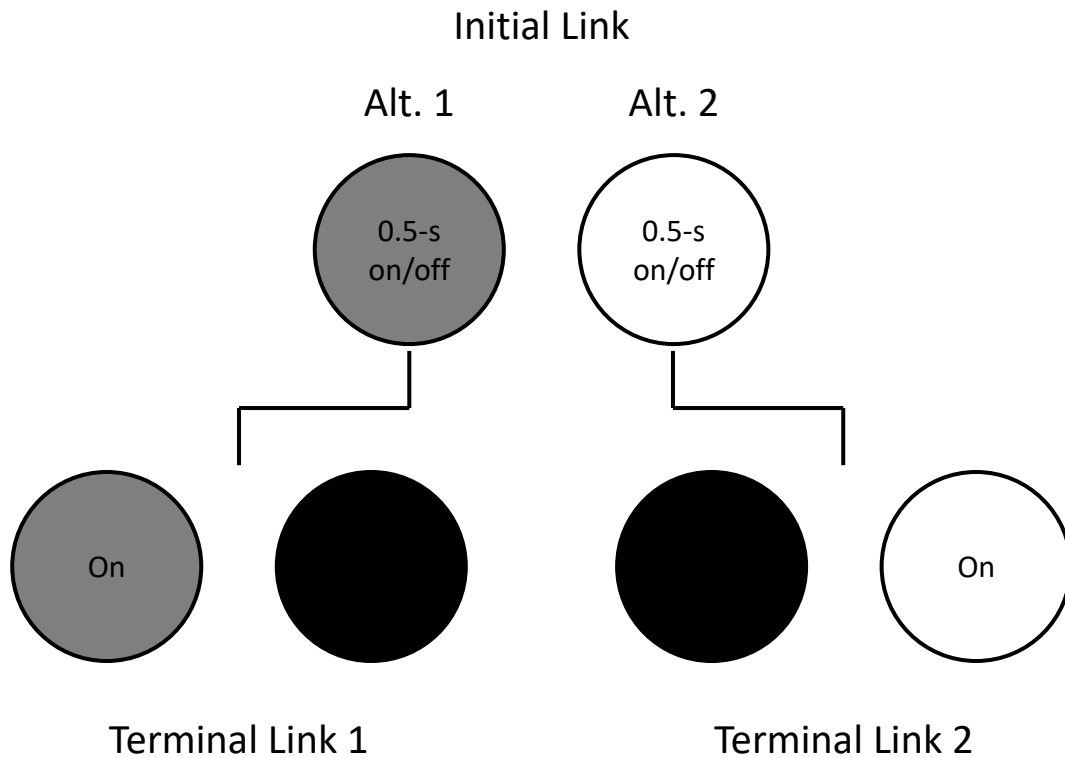
Figure *7*.1. Diagram the concurrent-chains procedure used in Experiment 5. Shaded and unshaded circles represent response keys lit yellow and white, respectively. During initial links, both keys flashed on/off every 0.5 s. During terminal links, only one key was lit constantly and the other was darkened. The contingencies arranged in each terminal link varied across conditions and are detailed in Table 7.1.

Upon entry into the left-key terminal link (hereafter Terminal Link 1), the left key stopped flashing and was lit yellow constantly, and the right key was darkened (see lower left arm in Figure 7.1). On entry into the right-key terminal link (hereafter Terminal Link 2), the right key stopped flashing and was lit white constantly, and the left key was darkened (see lower right arm in Figure 7.1). Both terminal links remained in effect for 60 s and the next initial link was presented immediately after the end of the previous terminal link (see also Nevin & Grace, 2000b). Each terminal link arranged food reinforcers on equal VI 60-s

schedules, and multiple reinforcers could be obtained within a single terminal link. Across

conditions, one of the terminal links also arranged brief stimulus presentations on a VI

schedule. Brief stimulus presentations were identical to those in Experiments 1, 2 and 4, and

consisted of the active key turning red before changing back to the discriminative stimulus

signalling the terminal link. Events scheduled but not obtained within a terminal link were

held until the next instance of the same terminal link. The location, schedule, and duration of

brief stimulus presentations varied across conditions, as in Experiment 4. Furthermore, in

some conditions food reinforcers replaced brief stimulus presentations to compare their

effects on preference. Table 7.1 shows the order of conditions, the schedule of food, and the

conjoint event scheduling in each terminal link.

Table 7.1
Schedules of food, and conjoint scheduling of food (*Food*) and brief-stimulus (*Stim*)
presentations in the terminal links in each condition of Experiment 5.

	Food schedule		Added schedule		
Condition	TL 1 (left)	TL 2 (right)	TL 1 (left)	TL 2 (right)	Sessions
1	VI 60 s	VI 60 s	-	Stim.: 0.5 s, VI 60 s	30
2	VI 60 s	VI 60 s	Stim.: 0.5 s, VI 60 s	-	30
3	VI 60 s	VI 60 s	Food: 2 s, VI 60 s	-	30
4	VI 60 s	VI 60 s	-	Food: 2 s, VI 60 s	30
5	VI 60 s	VI 60 s	-	-	60
6	VI 60 s	VI 60 s	Stim.: 2 s, VI 60 s	-	30
7	VI 60 s	VI 60 s	Stim.: 2 s, VI 15 s	-	30
8	VI 60 s	VI 60 s	Food: 2 s, VI 15 s	-	30

In the first pair of conditions, brief stimulus presentations were first arranged in

Terminal Link 1, and then in Terminal Link 2. If brief stimuli have reinforcement-like effects,

the transition from Condition 1 to Condition 2 should shift preference in the initial link away

from the left key (Terminal Link 1) and towards the right key (Terminal Link 2).

As a control comparison, food presentations replaced the brief stimulus presentations

in Terminal Link 2 in Condition 3, and were then shifted to Terminal Link 1 in Condition 4. If

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food presentations have reinforcement effects, the transition from Condition 3 to Condition 4 should shift preference in the initial link away from the right key (Terminal Link 2) and towards the left key (Terminal Link 1).

Condition 5 sought to re-establish equal response rates between the two terminal links (i.e., indifference) by removing the additional food schedule arranged in Terminal Link 2. Therefore, both terminal links arranged equal VI 60-s schedules of food reinforcement only for 60 sessions. Pigeon 56 stopped responding during Condition 5. To maintain responding, the VI 60-s schedules were replaced with VI 30-s schedules from Condition 5 onward for Pigeon 56 only.

Similar to Experiment 4, Condition 6 assessed the effects of longer brief stimulus presentations by arranging 2-s presentations in Terminal Link 1. Condition 7 then assessed preference when the rate of brief stimulus presentations was increased to a VI 15-s schedule (a four-fold increase). For Pigeon 56 only, the rate of brief stimulus presentations was increased from VI 30 s to VI 7.5 s (also a four-fold increase). Lastly, Condition 8 again replaced brief stimuli with food reinforcers, using the same 2-s duration and VI 15-s schedule, to assess the difference in preference resulting from brief stimulus and food presentations. Any changes in preference between Conditions 2 to 3 and between Conditions 7 to 8 provide an index of the differences in reinforcement effects between the food and brief stimulus events.

7.2.3 Dependent measures

Preference was assessed by calculating log response ratios from responses in the initial link (see e.g., Grace & Nevin, 1997, 2000; Nevin & Grace, 2000b). We also calculated log response ratios from responses in the terminal link. However, as with previous concurrent-chains research (e.g., Autor, 1969; Herrnstein, 1964; Nevin & Grace, 2000b; Schwartz, 1969),

terminal link response ratios were insensitive to variations in reinforcement contingencies and are therefore presented in Appendix Figure A7.2.

We further quantified the effects of brief stimulus and food presentations using a generalised matching analysis (e.g., Baum, 1974; Grace, 1994; Grace & Nevin, 1997). Preference in concurrent chains can be measured as the log ratio of response rates in the initial link as a function of the log ratio of reinforcer rates in the terminal links. The relation between these variables typically is linear and has been accurately described by Equation 1.9, repeated here for convenience:

$$\log\frac{B_{i1}}{B_{i2}} = a_r\log\left(\frac{R_{t1}}{R_{t2}}\right) + \log c_r \qquad (7.1)$$

where B_{i1} and B_{i2} are the response rates in the initial links to Alternatives 1 and 2, respectively, and R_{t1} and R_{t2} are the reinforcer rates in the corresponding terminal links. a_r is the sensitivity parameter and scales the effect of the reinforcer ratio on response allocation and log c_r captures any inherent bias between the alternatives independent of the obtained reinforcer ratio. The slope a_r can be used to index the extent to which the log response ratio changes as the log reinforcer ratio is varied.

Log response ratios in the initial link were averaged across the last 10 sessions of each condition, and plotted against the log obtained event ratios in the terminal links. Stability of the data in the last 10 sessions was assessed using a similar analysis as Elliffe et al. (2008) and detailed in Appendix A7. Across conditions, we arranged 5:1, 2:1, 1:1, and 1:2 ratios of food reinforcer rates across the two terminal links (Conditions 8, 3, 5, & 4, respectively), and the same 5:1, 2:1, 1:1, and 1:2 ratios of overall event rates in conditions arranging brief stimulus presentations (Conditions 7, 2 & 6, 5, & 1, respectively). The rate of food reinforcers was constant and equal across these later conditions, and only the rate of brief stimulus presentations differed. Therefore, any change in the log response ratio would be due to

changes in the arrangement of brief stimulus presentations. Fitting linear regressions to the data allowed us to compare the slope parameters (i.e., sensitivity) of food versus brief-stimulus functions, and quantify the extent to which response ratios changed as the ratio of food versus brief stimulus presentations varied across conditions.

7.3 Results

Table 7.2 shows mean baseline responses per min in the initial link, and obtained event presentations per hr in the terminal links. In general, obtained event presentation rates were slightly lower than but nevertheless approximated the scheduled rates across conditions. Figure 7.2 shows log response ratios in the initial link (filled data points) and log food-reinforcer ratios in the terminal link (unfilled data points) across successive sessions and conditions. Successive conditions are separated by dotted vertical lines. Circles above or below the x-axis (set at $y = 0$) indicate the presence of a conjointly arranged brief-stimulus schedule in the corresponding terminal link, with the duration and schedule summarised by the accompanying text. Therefore, reinforcement-like effects of brief stimulus presentations can be indexed by the level of preference toward the circles.

Table 7.2

Mean responses per min to the alternatives in the initial link (IL) and obtained food and brief stimulus presentations per hr in the terminal links (TL) in Experiment 5.

Pigeon	Condition	Responses per min		Foods per hr		Stimuli per hr	
		IL 1	IL 2	TL 1	TL 2	TL 1	TL 2
51	1	18.40	23.29	56.00	56.00	-	58.00
	2	23.01	27.11	57.00	53.50	56.00	-
	3	52.29	13.57	57.50	51.00	56.00[a]	-
	4	3.39	70.54	52.50	56.50	-	57.50[a]
	5	11.73	69.10	56.00	57.00	-	-
	6	14.04	60.79	56.00	51.00	56.00	-
	7	12.88	60.45	67.50	54.00	235.00	-
	8	85.51	5.39	71.00	53.50	236.00[a]	-
52	1	8.44	9.83	51.50	57.50	-	57.50
	2	4.97	8.87	53.00	50.50	58.50	-
	3	9.68	3.94	54.50	55.50	56.00[a]	-
	4	2.62	10.01	49.50	50.50	-	51.00[a]
	5	10.83	5.23	53.50	53.50	-	-
	6	7.26	5.39	55.00	54.00	54.50	-
	7	8.22	6.78	67.50	55.00	228.50	-
	8	17.37	1.67	69.50	55.00	235.00[a]	-
53	1	23.83	13.62	54.00	55.00	-	56.00
	2	23.87	14.25	57.50	52.50	56.50	-
	3	68.31	3.98	57.00	55.50	54.00[a]	-
	4	17.27	37.18	55.00	57.50	-	57.00[a]
	5	30.62	14.80	54.50	54.00	-	-
	6	41.13	16.86	56.50	53.00	57.00	-
	7	39.27	16.20	65.00	54.00	231.50	-
	8	87.13	4.75	61.50	53.50	227.50[a]	-
54	1	1.80	1.73	33.50	30.50	-	28.50
	2	2.26	2.82	46.50	42.50	50.50	-
	3	10.34	6.94	57.00	54.50	58.50[a]	-
	4	2.16	16.91	51.00	58.50	-	57.00[a]
	5	2.85	4.18	47.50	51.00	-	-
	6	5.57	10.10	57.00	53.50	56.00	-
	7	3.71	11.27	65.50	54.00	229.00	-
	8	50.42	1.98	69.00	53.50	240.50[a]	-
56	1	5.88	9.20	49.50	47.00	-	50.50
	2	4.98	3.56	31.50	25.50	30.50	-
	3	2.05	1.49	27.00	27.00	28.00[a]	-
	4	1.50	9.95	37.00	38.50	-	36.50[a]
	5	3.94	8.77	79.50[b]	83.50[b]	-	-
	6	6.14	6.70	118.00[b]	109.50[b]	118.50[b]	-

7	10.58	7.89	143.50 [b]	107.50 [b]	423.50 [c]	-
8	19.29	2.04	141.50 [b]	116.00 [b]	438.00[ac]	-

[a] The added schedule in Conditions 3, 4 and 8 arranged food presentations instead of brief stimulus presentations for all pigeons.

[b] During Condition 5 and in all subsequent conditions, the VI 60-s schedules were replaced with VI 30-s schedules for Pigeon 56 only.

[c] During Condition 7 and 8, the added VI schedule was VI 7.5 s for Pigeon 56 only.
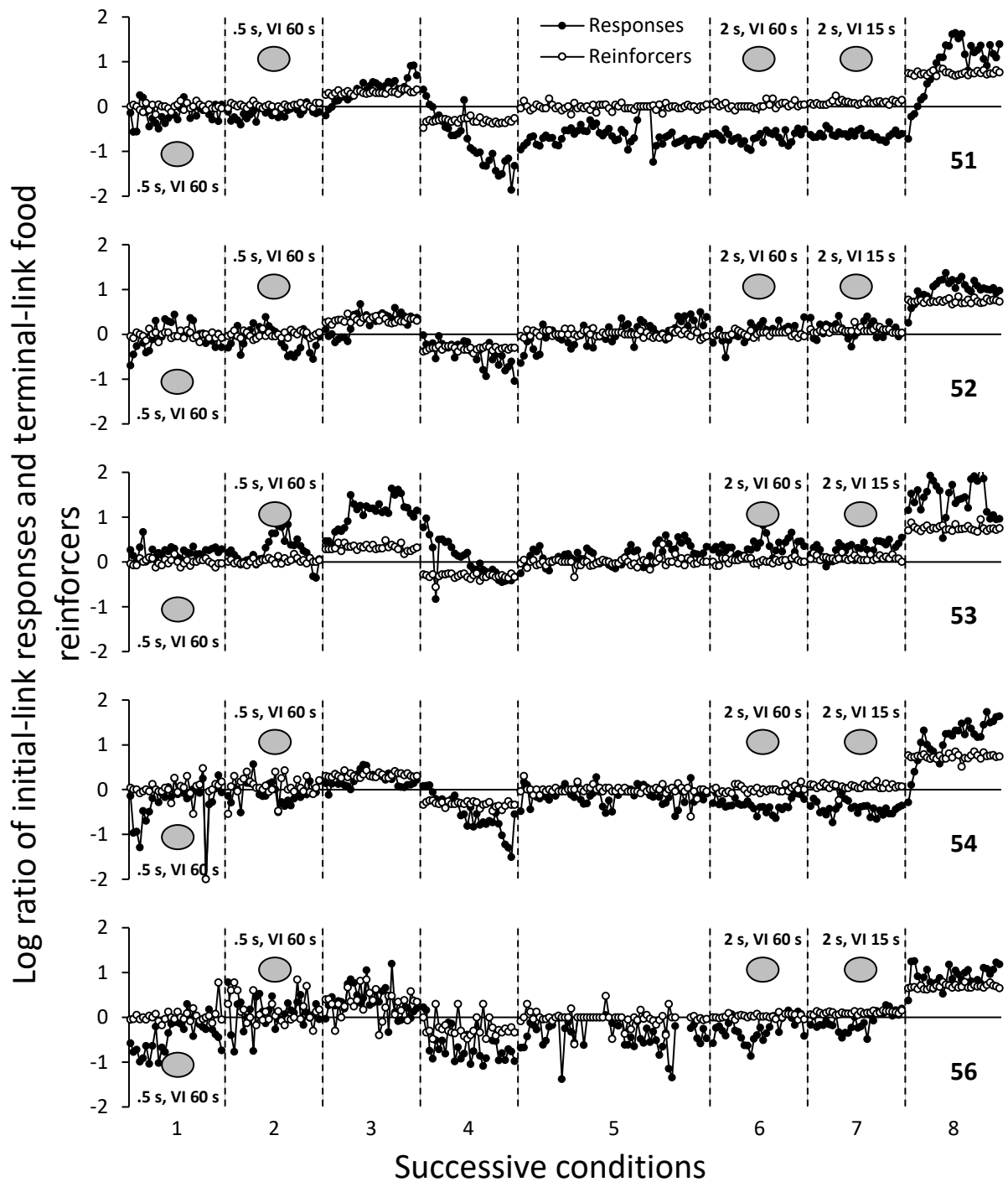
Figure 7.2. Log response ratios in the initial link (filled data points) and log obtained food reinforcer ratios in the terminal link (unfilled data points) across successive sessions and conditions for individual pigeons in Experiment 5. The operation of an additional brief-stimulus schedule is indicated by circles above/below the *x*-axis, and the duration and schedule of brief stimulus presentations is given in the accompanying text.

There were no systematic effects of brief stimulus presentations on preference in any condition. The log ratio of responses fluctuated around zero (indifference) for Conditions 1 and 2, despite a change in the location of brief stimulus presentations across the two conditions. For Pigeon 56, there was greater variability in both log reinforcer ratios and log response ratios due to low absolute rates of responding. For all pigeons, both log reinforcer ratios and log response ratios shifted towards Terminal Link 1 immediately when brief stimulus presentations were replaced with food in Condition 3, and remained high until the location of food was changed to Terminal Link 2 in Condition 4.

There were considerable differences in preference in Condition 5 when the additional food schedule was removed and both terminal links arranged equal VI 60-s schedules of food. For three pigeons (51, 54, and 56), preference did not return to indifference even after 60 sessions of equal reinforcer rates but remained toward Terminal Link 2. For the other two pigeons, preference shifted slightly toward Terminal Link 1 (52 and 53). Reintroducing brief stimulus presentations in Terminal Link 1 with a longer duration (Condition 6) and arranging a richer schedule of brief stimulus presentations (Condition 7) failed to shift preference for all pigeons. However, when brief stimulus presentations were replaced with food in Condition 8, both log reinforcer ratios and log response ratios rapidly shifted towards Terminal Link 1 for all pigeons.

Figure 7.3 shows the generalised matching analysis (Equation 7.1), plotting log response ratios as a function of log event ratios for conditions with additional brief stimulus presentations (filled data points) and food reinforcers (unfilled data points). Fitted linear regressions are shown by dotted lines, and the slope, intercept, and r^2 values are shown in Table 7.3. Condition 5 (1:1 reinforcer ratio with no brief stimulus presentations) was used in fitting both functions for the log obtained event ratio at 0. The slopes of the fitted functions were reliably steeper for food than brief stimuli. Sensitivity values ranged from 1.45 to 2.49

($M = 1.89$, $SD = 0.38$) for food functions (see also Grace & Nevin, 2000; Nevin & Grace,

2000b). In contrast, the sensitivity values for brief-stimulus functions ranged from -0.33 to

0.58 ($M = 0.02$, $SD = 0.36$), with three of the five pigeons showing a negative slope (51, 52,

and 54). Therefore, preference in the initial links shifted systematically when varying food

reinforcers across conditions, but not when varying brief stimulus presentations. The intercept

(i.e., bias) values varied across pigeons, but were consistent across food and brief-stimulus

functions for individual pigeons. Greater variance was accounted for with the food functions

(mean $r^2 = 0.94$) than for brief-stimulus functions (mean $r^2 = 0.26$) due to the unsystematic

variation in the data from brief-stimulus conditions.

Table 7.3
Parameter values of the fitted regressions in Figure 7.3. *a* and log *c* represent the slope
and intercept values, respectively.

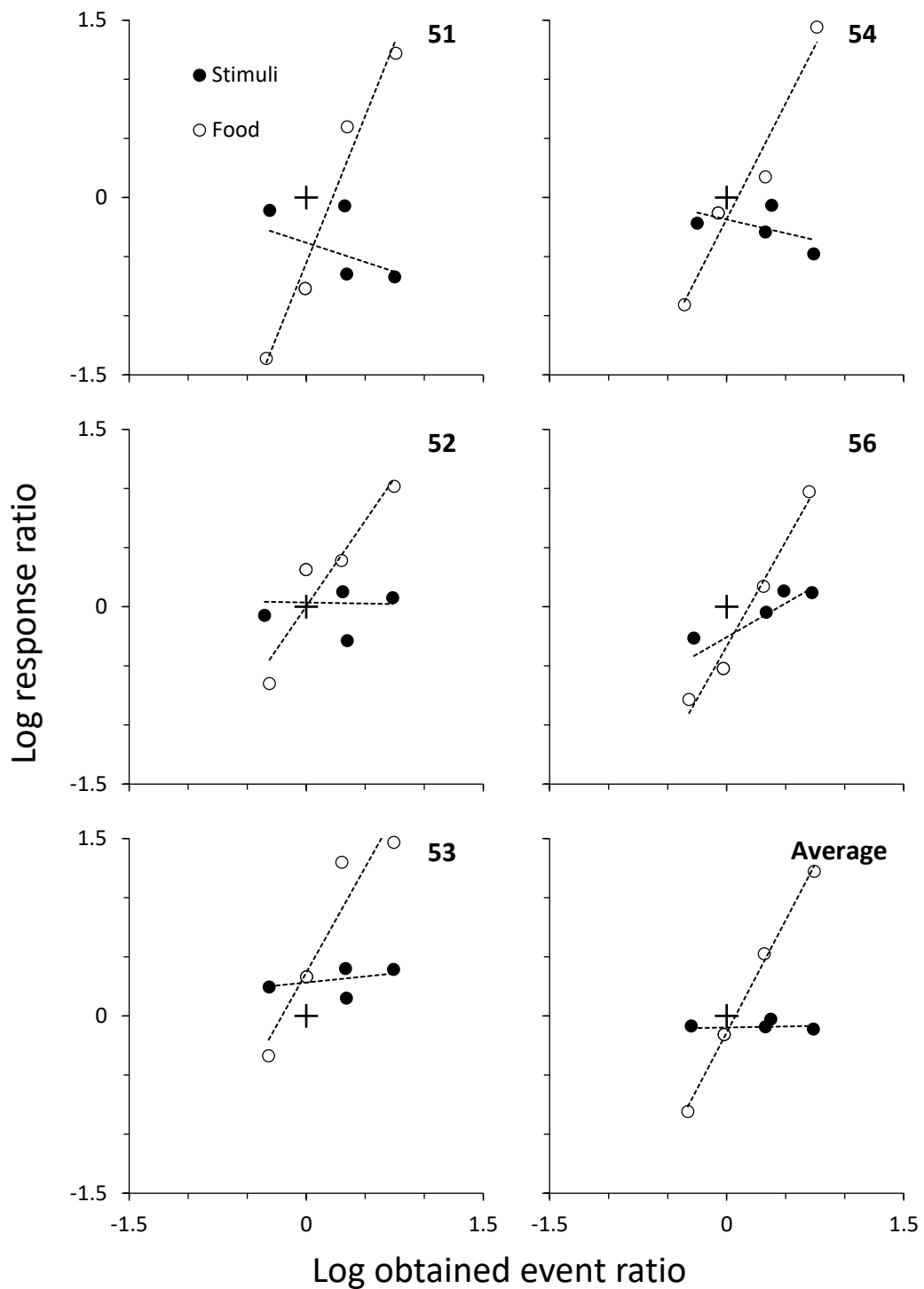| Subject	Brief stimuli			Food		
	a	log *c*	r^2	*a*	log *c*	r^2
51	-0.33	-0.38	0.15	2.49	-0.55	0.97
52	-0.02	0.04	0.00	1.45	0.00	0.90
53	0.10	0.28	0.15	1.78	0.37	0.90
54	-0.23	-0.19	0.33	1.96	-0.18	0.95
56	0.58	-0.26	0.68	1.77	-0.34	0.98
Mean	0.02	-0.10	0.26	1.89	-0.14	0.94

Figure 7.3. Generalised matching analyses on data from conditions arranging additional brief stimulus presentations (filled data points) and food reinforcers (unfilled data points) for individual pigeons in Experiment 5. Fitted linear regressions are shown by dotted lines. The bottom right panel shows group average data.

7.4 Discussion

The present experiment failed to find evidence that brief stimuli unrelated to food affect preference in the same manner as food reinforcers. Varying a schedule of brief stimulus presentations in the terminal links of a concurrent-chains schedule did not shift preference in the initial link. Additionally, increasing the duration and rate of brief stimulus presentations also failed to shift preference. In contrast, varying an additional food schedule reliably produced large shifts in preference. A generalised matching analysis confirmed that preference changed reliably when the ratio of food reinforcers was varied, but preference was generally insensitive to variations in brief stimulus presentations.

Consistent with previous findings using constant-duration terminal links, fitting Equation 7.1 resulted in high levels of sensitivity when presenting different ratios of food reinforcers across conditions (e.g., Grace & Nevin, 1997; Nevin & Grace, 2000b). The mean sensitivity value in the present study was 1.89 (*range* = 1.45 to 2.49), similar to the mean value found by Nevin and Grace (2000b; M = 1.78, *range* = 1.39 to 2.10) and Grace and Nevin (2000; M = 2.13, *range* = 1.38 to 2.76). In contrast, the mean sensitivity for brief-stimulus functions was 0.02 (*range* = -0.33 to 0.58), and the linear regressions were poor fits due to the unsystematic scatter in the data (mean r^2 =0.26). These model fits show that preference did not shift systematically when manipulating the location and rate of brief stimulus presentations. Therefore, brief stimuli did not affect preference to the extent that food presentations did, and did not do so in a consistent direction.

A possible confound in our analysis is that the brief-stimulus functions in Figure 7.3 were calculated by summing the rate of obtained food and brief stimulus presentations. This was necessary to have a defined numerator and denominator, as brief stimulus presentations were only arranged in one terminal link in any one condition. However, this may also

artificially flatten the function if the reinforcement-like effects of brief stimuli were much weaker than the reinforcement effects of food. However, the flat and sometimes negative slopes in the brief-stimulus functions provide strong evidence that no simple weighting function would reveal any reinforcement-like effects of brief stimuli. An alternative course for future studies is to arrange brief stimulus presentations in both terminal links, and vary their rates across conditions while maintaining constant and equal rates of food reinforcement (cf. Podlesnik et al., 2009, with multiple schedules). We decided against this course because the findings across all five experiments showed no indication of reliable reinforcement-like effects of brief stimuli unrelated to food.

The generalised matching analysis used mean log response ratios averaged from the

last 10 sessions of each condition. We assessed the stability of the data in the last 10 sessions

by splitting the 10 sessions into two blocks of five, and assessing the correlation between

average log response ratios in the first five sessions and the log response ratios in the last five

sessions (see also Elliffe et al., 2008). Figure A7.1 shows responding in the first five sessions

were highly correlated with responding in the last five sessions (Person's $r = 0.94$). Therefore,

despite a few outliers, log response ratios were fairly stable and representative in the last 10
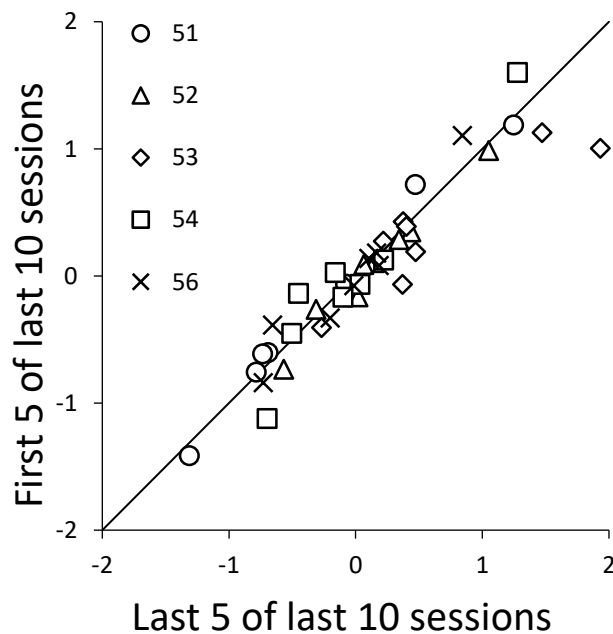
sessions of each condition.

Figure A7.1. Log response ratios in the last 10 sessions of each condition. Mean log response ratios in the first five sessions are plotted as a function of the mean log response ratios in the last five sessions.

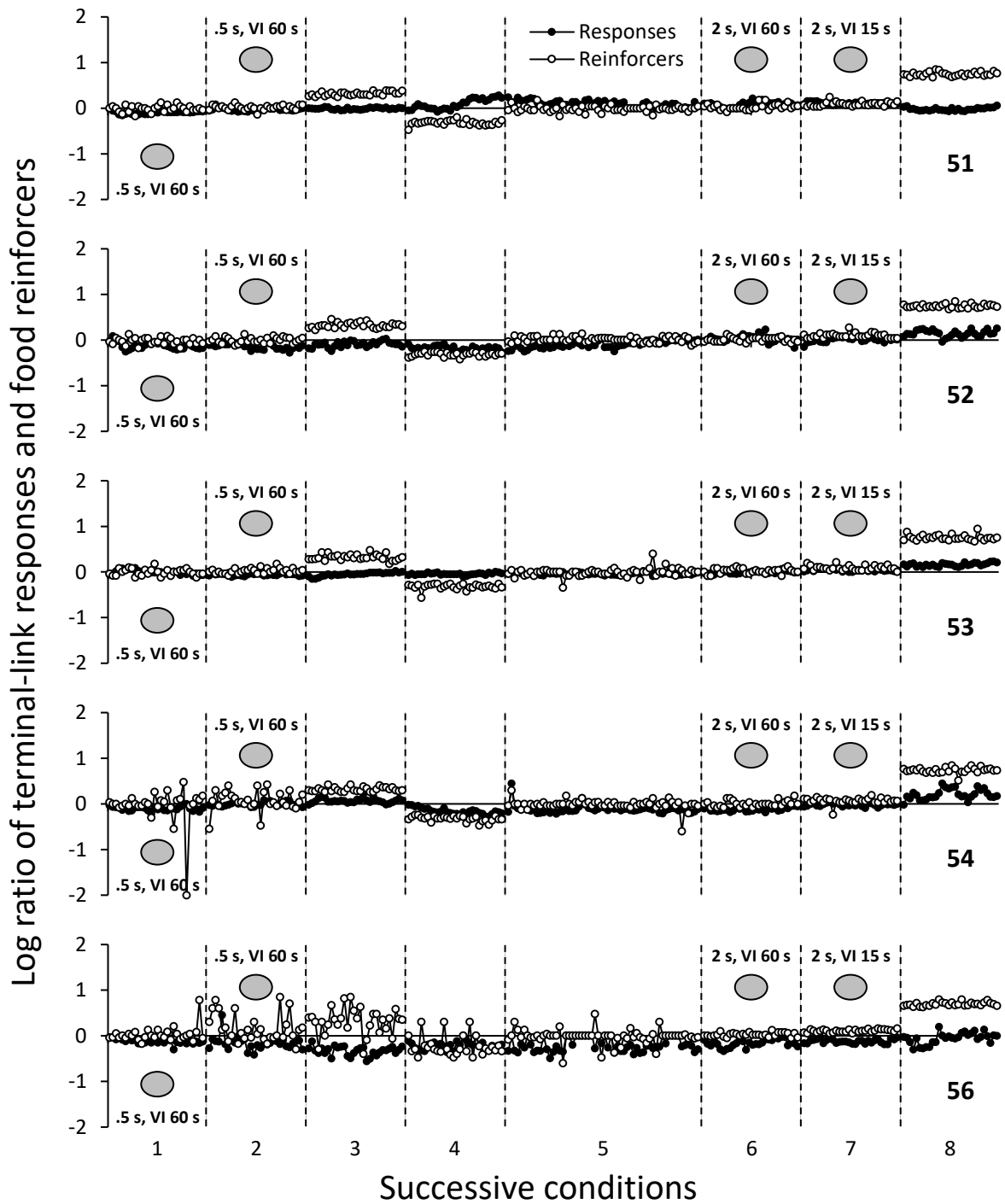Figure A7.2. Log response ratios (filled data points) and log obtained food reinforcer ratios (unfilled data points) in the terminal links across successive sessions and conditions for individual pigeons in Experiment 5. The operation of an additional brief-stimulus schedule is indicated by circles above/below the *x*-axis, and the duration and schedule of brief stimulus presentations is given in the accompanying text.

Chapter 8

8.1   *Summary of results*

The present set of experiments attempted to replicate and extend previous findings showing reinforcement-like effects of brief stimuli with no programmed relation to food reinforcers (Reed & Doughty, 2005; Podlesnik et al., 2009). Similar to the previous studies, Experiments 1 through 4 assessed relative response rates and resistance to change across components of a multiple schedule, with one component arranging an additional schedule of brief stimulus presentations. Experiment 5 then attempted to assess the effects of brief stimuli using a more sensitive measure, preference in a concurrent-chains procedure. Local response rates, relative response rates, relative resistance to change, and preference all failed to reveal reliable reinforcement-like effects of brief stimuli unrelated to food. In contrast, equivalent rates of food presentations more systematically impacted local response rates (Experiments 1 and 2), relative resistance to change (Experiment 4) and preference (Experiment 5).

8.2   *Comparison with Reed and Doughty (2005)*

Reed and Doughty (2005) found higher response rates and greater resistance to change in a component arranging a conjoint brief stimulus schedule, compared with a component without brief stimuli. We attempted to replicate their findings by arranging a two-component multiple schedule with the same schedules of food and brief stimuli, and the same conjoint scheduling of both events. We assessed their key condition a total of 5 times over 3 groups of pigeons (Experiment 1, Conditions 1 and 3; Experiment 2, Condition 2; Experiment 3, Condition 1; and Experiment 4, Condition 2), but nevertheless failed to replicate their findings; neither response rates nor resistance to change was reliably greater in the component arranging brief stimuli.

The difference in results is likely because the present experiments differed from Reed and Doughty's (2005) study in a number of ways. We used different species (pigeons vs. rats), different responses (key pecking vs. lever pressing), and different stimuli (visual vs. auditory). In addition, the brief stimulus used in the present study was localised on the active response key, whereas Reed and Doughty used a diffuse tone. Therefore, the difference in results may be due to one or a combination of factors. Further, these contrasting findings suggest that the effects of conjointly arranged brief stimuli may have limited generality across one or more of these procedural differences. The controlling variables responsible for the different results between the present study and Reed and Doughty's have yet to be identified. To establish the reliability and generality of Reed and Doughty's findings, future studies should directly replicate Reed and Doughty's experiment using the same species and procedure, before systematically exploring the generality of the effects across different procedural conditions (see Sidman, 1960, for discussion).

8.3   *Comparison with Podlesnik et al. (2009)*

The species, response, and stimuli used in the present experiments were more similar to Podlesnik et al.'s (2009) study. Podlesnik et al. found that brief stimuli unrelated to food did not influence response rates but systematically increased resistance to change. We attempted to replicate their findings by programing identical contingencies of food and brief stimulus presentations but were initially unsuccessful because the pigeons were biased towards the right yellow key (Experiment 1). We then replicated Podlesnik et al.'s procedure with a different group of pigeons, after assessing for pre-existing biases, and still failed to replicate Podlesnik et al.'s findings (Experiment 2). Then, to address remaining procedural differences between Experiments 1 and 2 and Podlesnik et al.'s experiment, we conducted experimental sessions in individual, lightproof, and sound-attenuating chambers with counterbalanced stimulus colours (Experiment 3). However, we were still unable to replicate

Podlesnik et al.'s findings. Therefore, in spite of the procedural similarities, we failed to replicate the findings that brief stimuli increased resistance to change.

To compare the results of Podlesnik et al. (2009) with the present findings, Figure 8.1 plots the data from Podlesnik et al. on the same axes as data from the present experiments (dark- and light-filled data points, respectively). Data were taken from all eight pigeons in the single condition of Experiment 1 in Podlesnik et al., and from 16 pigeons across eight conditions in the present study (Experiment 1, Conditions 1 and 3; Experiment 2, Condition 2; Experiment 3, Condition 1; and Experiment 4, Conditions 2, 3, 4, and 6). Circles and triangles represent data from conditions arranging VI 60-s and VI 15-s schedules of brief stimulus presentations, respectively. Figure 8.1 plots baseline responses per min (left panel) and log proportion of baseline response rates (right panel) in the component without brief stimuli (*y*-axis), as a function of the same measures in the component with brief stimuli arranged conjointly (*x*-axis). Data points above the dotted diagonal show greater response rates or resistance to change in the component without brief stimuli, whereas data points below the dotted diagonal show greater response rates or resistance to change in the component with brief stimuli. The extent to which response rates or resistance to change differed across components can be indexed by the distance between the data points and the dotted diagonal.
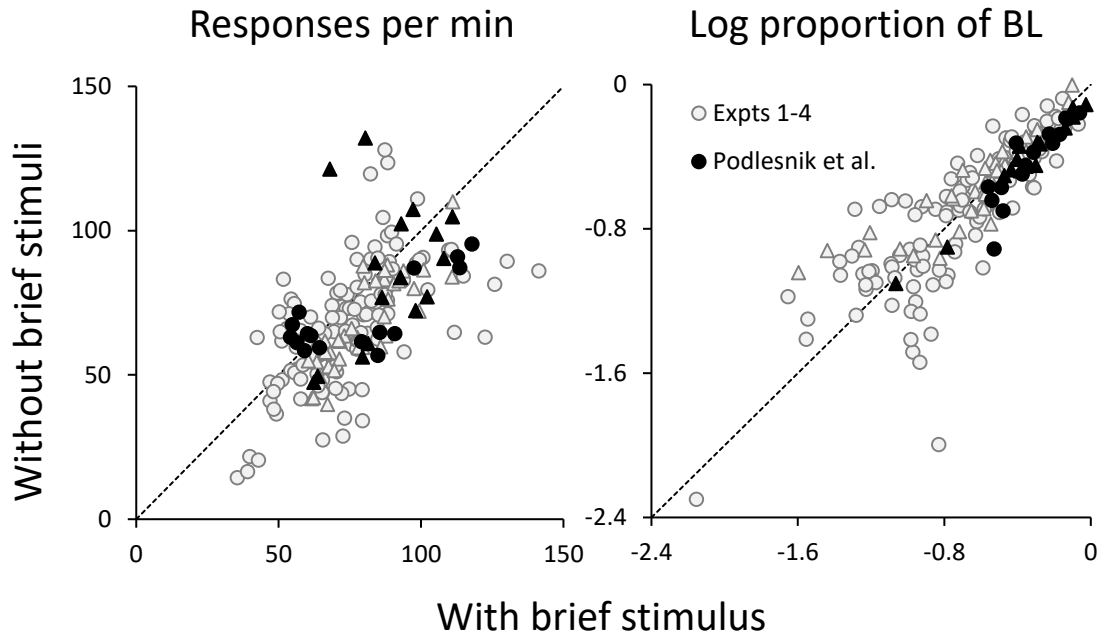
Figure 8.1. Baseline response rates (left panel) and resistance to change (right panel) in the component without brief stimulus presentations, as a function of the same measures in the component with brief stimulus presentations. Data are presented from the present study (light-filled data points) and from Podlesnik et al. (2009; dark-filled data points). Circles and triangles are from conditions arranging VI 60-s and VI 15-s schedules of brief stimulus presentations, respectively.

Data points representing response rates (left panel) in both Podlesnik et al.'s (2009) experiment and the present study varied unsystematically around the diagonal. Thus, there were no systematic effects of brief stimuli on response rates in either study. In contrast, 30 out of 32 data points (94%) representing resistance to change (right panel) in Podlesnik et al.'s experiment fell below the diagonal. In the present study, only 70 of the 167 data points (42%) representing resistance to change fell below the diagonal. Resistance to change was more variable when responding was disrupted to greater extents. Therefore, a fairer comparison between the two datasets would be to assess only the data points falling within the same range as that found by Podlesnik et al.: When only data points within the maximum and minimum *x*- and *y*-coordinates of Podlesnik et al.'s data are considered, 57 out of 129 data points from the current study (44%) fell below the diagonal. When the range is narrowed further to

exclude the three outlying data points in Podlesnik et al.'s data, 34 out of 74 (46%) fell below the diagonal. Therefore, the failure to replicate Podlesnik et al.'s finding of increased resistance to change was not due to differences in overall levels of disruption.

Inspection of Podlesnik et al.'s (2009) data in Figure 8.1 shows that almost all data points fell close to the diagonal. This suggests that brief stimuli had only a small effect in increasing resistance to change. Similar deviations from the diagonal were found in the present study, but in both directions. Thus, overall we found no systematic effects of brief stimuli on resistance to change.

8.4   *A possible analogue in Pavlovian conditioning*

Reed and Doughty (2005) and Podlesnik et al.'s (2009) findings are surprising because brief stimuli exhibited reinforcement-like effects despite having no programmed relation with food reinforcers. However, it is possible that their findings were due to adventitious (i.e., chance) pairing of the brief stimuli and food. If both events were arranged on any given response, the event arranged first would be presented (see Podlesnik et al., 2009). Therefore, it is possible that individual pigeons might encounter the chain of events: Response-Stimulus-Response-Food. Exposure to this chain early in training might result in the subjects associating the occurrence of brief stimuli and food. However, the effects of these adventitious pairings should decrease with prolonged exposure to the programmed contingencies, because pigeons were equally likely to encounter the inverse chain: Response-Food-Response-Stimulus.

There is precedent in the Pavlovian literature for thinking that adventitious pairings might lead to associations between stimuli, despite no programmed relation. In Rescorla's "truly random control procedure" (1967, pp. 73; see also Rescorla, 1966), presentations of the conditioned stimulus (CS) and the unconditioned stimulus (US) are arranged on independent

schedules, such that there is no relation between CS and US presentations. Therefore, both events are presented randomly in time, similar to the conjoint VI schedules in the present set of experiments. Despite there being no programmed relation between CS and US presentations, a number of studies have found conditioned responding to the CS (e.g., Kremer & Kamin, 1971; Quinsey, 1971). Importantly, conditioning to the CS seems to depend on chance pairings of CS-US occurring early in training (Benedict & Ayres, 1972; see Papini & Bitterman, 1990, for discussion).

It is possible that, as in Rescorla's (1967) truly random control procedure, pigeons responding on conjointly arranged brief stimuli and food schedules might have associated the occurrence of brief stimuli and food given early exposure to Response-Stimulus-Response-Food chains. Furthermore, insufficient exposure to this chain of events might explain why pigeons in the present study did not associate brief stimuli and food. However, the specifics of what constitutes "early" and "sufficient" exposure have yet to be determined. Future studies can directly assess the role of early pairings by varying the probability of Response-Stimulus-Response-Food chains in the initial sessions of training (see Benedict & Ayres, 1972, for a related manipulation).

8.5   *On the failure to replicate previous findings*

The present failure to replicate the reinforcement-like effects of brief stimuli unrelated to food does not imply a fault in the original studies. Indeed, both Reed and Doughty (2005) and Podlesnik et al. (2009) replicated their findings across subjects, and across different disruption tests within-subjects. Therefore, both studies already demonstrate intersubject and intrasubject replication (Sidman, 1960). Instead, the discrepancy between the present data and previous findings suggests that the controlling variables responsible for the reinforcement-like effects of brief stimuli have yet to be identified (see Davison, 1988, for related discussion).

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Sidman (1960) argued persuasively that there is "no middle ground" (pp. 94) for experiments failing to replicate previous results, and suggested that it is the experimenter's responsibility to identify the factors responsible for the discrepancy in results. The preceding sections highlighted key differences in methodology and one possible explanation for the failure to replicate Reed and Doughty's (2005) and Podlesnik et al.'s (2009) findings. Further discussion of other possible factors is complicated by the novelty of the previous findings and relies primarily on speculation. Nevertheless, a number of theoretical discussions can inform how future experiments might be designed to test possible influencing factors.

The novelty of Reed and Doughty's (2005) and Podlesnik et al.'s (2009) findings makes it difficult to account for why the present set of experiments failed to replicate their effects. No theoretical account of reinforcers (e.g., Baum, 2005), nor reinforcer-related stimuli (e.g., Williams, 1994; Shahan, 2010), would predict that seemingly arbitrary brief stimuli should have reinforcement-like effects. Furthermore, the functional definition of reinforcers does little more than classify the stimuli in previous studies as reinforcers. A passage from Killeen (1972) describes the current situation aptly: "Sometimes the effect on behavior is more obvious or easily measured than the independent variables that bring about the effect. In these cases it is tempting to nominate an event as a punisher, conditioned reinforcer, or primary reinforcer of a particular utility, because of its effects, and to use it as such without always having a complete understanding of the conditions necessary for its efficacy." (pp. 494). The present study has attempted to replicate the reinforcement-like effects of brief stimuli unrelated to food reinforcers, but failed to identify the necessary conditions for these effects. Future studies are needed to determine exactly what conditions are necessary for brief stimuli to acquire reinforcement-like effects.

8.6   Future directions

The course of future studies can be informed by theoretical discussions in other programmes of research. For example, Davison and McCarthy (1988, pp. 251) describe the attempt to use novel experimental procedures to demonstrate the generality of an effect as a "knight's move". This research strategy may prove fruitful if the effect is replicated, because it demonstrates broad generality of the underlying processes responsible for the effect (see also Sidman, 1960). However, failure to find the effect with a novel procedure does little to specify the boundary conditions of the original effect.

The study of brief stimuli with no relation to reinforcers can be seen as a departure from a larger literature assessing the effects of brief stimuli with programmed relations to primary reinforcers (see Chapter 2). Therefore, the present set of experiments represent one end of the spectrum of possible relations that might be arranged. Successful and reliable demonstration of reinforcement-like effects of stimuli unrelated to reinforcers could prove useful in highlighting the limitations of our current understanding of reinforcers, and for exploring the characteristics that distinguish reinforcers from other environmental stimuli. However, given the failure to find robust reinforcement-like effects, future studies should backtrack and systematically assess the effects of brief stimuli with more explicit relations with food.

For example, brief stimuli paired with the onset of primary reinforcers have been studied extensively yet their effects on behaviour remain poorly understood. Brief stimuli presented immediately before a reinforcer increase response rates when reinforcers are arranged on a variable-ratio schedule (e.g., Reed, Schachtman, & Hall, 1988), but decrease response rates when reinforcers are arranged on a VI schedule (e.g., Pearce & Hall, 1978). Nevertheless, brief stimuli in the latter case can increase resistance to change (e.g., Bell et al.,

2007; Roberts, Tarpy, & Lea, 1984). The mechanisms responsible for these disparate effects are still poorly understood. Therefore, future studies could investigate the (sometimes) reinforcement-like effects of these stimuli using similar procedures and analyses as those employed by the present study.

In sum, while the present study failed to replicate reinforcement-like effects of brief stimuli unrelated to food reinforcers, it demonstrates a systematic series of experiments that can be used to assess the reinforcement-like effects of stimuli with other relations to primary reinforcers. Using similar sets of conditions with other programmed relations between food and brief stimulus presentations could be a fruitful approach to identifying the necessary conditions that produce reinforcement-like effects of brief stimuli. Therefore, the present study could contribute towards developing a standardised paradigm that would enhance the replicability of experimental findings (see Bradley, 2017, for related discussion).

8.7   *Behavioral momentum and reinforcement*

Behavioral momentum theory (Nevin & Grace, 2000a) provides a theoretical and practical framework to assess potential reinforcement-like effects of brief stimuli. Reinforcers are understood to affect behaviour via two separable relations; where response rate is determined by the response-reinforcer relation, and resistance to change is determined by the stimulus-reinforcer relation. The specification that separable processes govern each measure could help resolve disparate effects of certain stimuli on response rates and resistance to change (e.g., Podlesnik et al., 2009, Roberts et al., 1984).

Furthermore, behavioral momentum theory describes how different measures of behaviour might index the same underlying construct (i.e., response strength). In particular, theoretical and empirical work by Nevin and colleagues (Grace & Nevin, 1997, 2000; Nevin, 1979; Nevin & Grace, 2000a, 2000b) showed that preference and resistance to change are

convergent measures of the effect of reinforcers. These studies established the foundation for the design of Experiment 5, which assessed potentially the same underlying process but with a more sensitive measure. Therefore, the present study demonstrates the utility of a theoretical framework unifying different measures of the effects of reinforcement on behaviour.

8.8   *Conclusion*

The present thesis failed to replicate previous findings showing reliable reinforcement-like effects of brief stimulus presentations unrelated to food reinforcers (Podlesnik et al., 2009; Reed & Doughty, 2005). Nevertheless, the current study represents a systematic approach to evaluating reinforcement-like effects from a behavioral momentum framework. The present study demonstrates a limit to the generality of previous findings and provides an initial step towards a standard paradigm to assess the reinforcement-like effects of stimuli with other programmed relations to reinforcers. An incremental programme of research using similar experimental strategies is likely to elucidate the conditions necessary for producing reinforcement-like effects of brief stimuli.

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