

EFFECTS OF REINFORCEMENT DURATION AND DURATION-CORRELATED STIMULI
ON
PREFERENCE IN PIGEONS

by

Michael J. Harman

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ABSTRACT

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Michael J. Harman

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Pigeons were trained in a two-key, concurrent chains choice procedure with equal initial and terminal links. Across conditions, the durations of reinforcement in the terminal links were either equal (3-s vs 3-s) or unequal (3-s vs 6-s), and these durations were either uncued by hopper lights (both white) or cued (3-s: white; 6-s: colored). The pigeons' choice responding leading to the longer duration of reinforcement was generally in the range of indifference with nondifferential hopper lights, but favored the longer duration with differential hopper lights. Taken together, the data suggest that differential hopper lights facilitated the discrimination of the longer reinforcement duration, and hence enhanced its control.

Keywords: reinforcer-magnitude, choice, duration of reinforcement, preference

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Introduction

Effects of Reinforcement Duration and Duration-Correlated Stimuli on Preference in Pigeons

Once a stimulus has been identified as a reinforcer, a common next step is to analyze how changes to that stimulus, or its governing contingency affect behavior. The magnitude of a reinforcer, for example, is a routinely manipulated variable and is often studied as an evocative variable to responding (Catania, 1979). In altering the magnitude of a reinforcer, some studies have altered the rate of reinforcement. This method alters the *overall* exposure to a reinforcer per unit of time and is perhaps best conceptualized as a molar change of reinforcement parameters. The alternative is to increase or decrease physical properties of specific instances of the reinforcing stimulus, methods best categorized in terms of molecular changes in magnitude. Though both methods represent relevant avenues of research in their own right, the current study is concerned with this latter manipulation.

The extant literature concerning learning and molecular manipulations of reinforcement magnitude demonstrates a clear interest in studying the effects of this variable. The resulting data, however, are somewhat inconsistent. For example, according to Neuringer (1967), “there have been inconclusive and apparently inconsistent results [obtained] from magnitude experiments” (p. 417). In some instances, changes in reinforcement magnitude have exerted relatively weak control over behavior, resulting in less than robust changes in behavior. In other instances, those same manipulations have exerted strong control over behavior resulting in significant and magnitude-correlated changes in behavior. Nonetheless, the fact that *some* studies have found that increases in the magnitude of reinforcement correlate to monotonic increases in behavior has produced a rather pervasive assumption: That increasing measures of reinforcement will result in

approximately linear increases in learning. The assumed relationship between experimental operations and behavior processes has been referred to as the linearity assumption (de Villiers, 1977). To shed light on the variable findings, a closer analysis of the representative literature is necessary. Examining differences between experiments may then reflect systematic variations in behavior as a result of study-to-study variations in methodology. As a result, a clearer conclusion concerning the effects of magnitude of reinforcement seems valuable and appropriate.

An important component to any variable is the means by which it is quantified and subsequently measured (Sidman, 1960). The current study is concerned exclusively with duration-based measures of reinforcer magnitude, but it is necessary to consider the following definitions as relevant for comparison purposes: reinforcer quantity (e.g., Grindley, 1929), volume (e.g., Wolfe & Kaplon, 1940), concentration (e.g., Guttman, 1953), and rate of reinforcement (e.g., Schneider, 1973).

The duration of access to a reinforcer has been previously established as a measure of magnitude (Catania, 1963b). However, the behavioral effects correlated to differential durations of reinforcement are relatively mixed and seem to be dependent, in part, on operational parameters. For example, some studies have investigated the effects of duration of reinforcement using a single response procedure. Kling and Schrier (1971) referred to this method as a “constant-reinforcement” method having “single shifts” (i.e., between session shifts) in magnitude (p. 631). The effects of duration manipulations are then evaluated by comparing stable measures of behavior (e.g., response rate) across conditions or across groups exclusively related to specific durations of reinforcement.

To this end, Catania (1963b) conducted a study to measure changes in pigeons’ response rates as a function increasing durations of access to grain as reinforcement for key-pecking.

Pigeons could peck a key light and grain was made available contingent on fulfilling a constant schedule of reinforcement (VI 120 s). Across conditions, Catania manipulated the duration of access to grain while maintaining consistency in all other variables (e.g., key light color, reinforcement schedule). Average response rates were calculated as a function of the varying reinforcement durations. The results indicated that the pigeons' response rates were not reliably correlated with the duration of reinforcement; thus, response rates remained reliably stable independent of the different reinforcement durations.

Catania (1963b) then investigated the extent to which relative response rates were correlated with *relative* reinforcement duration in a concurrent operants procedure. The pecking on each of two keys was reinforced by differing durations of reinforcement according to a concurrent VI VI schedule. Responses on one key led to a constant duration of access to grain and responses on the other key led to a varied duration of access depending on the condition. The relative rate of pecking was now directly proportional to the duration of reinforcement: The pigeons responded faster on the key with the larger magnitude of reinforcement. Kling and Schrier (1971) referred this method as a “variable-reinforcement” procedure with “repeated shifts” (i.e., within session shifts) in reinforcement magnitude (p. 631). That is, a subject will repeatedly contact varying durations of reinforcement within a given session, typically in the form of high- and low-magnitude components or concurrently available choices. Thus, under these session parameters the duration of reinforcement can apparently evoke correlated changes in rates of responding, in line with the assumption of linearity.

It can then be tentatively concluded that when reinforcement duration is manipulated across conditions in single-response procedures, different reinforcement durations may have little control over behavior. In multiple response procedures, the subject's behavior may be better

controlled by the magnitude of reinforcement as the contingencies of reinforcement specify a direct correlation between responses and magnitude of reinforcement. That one response is correlated with one magnitude of reinforcement and the other with a different magnitude increases the probability that responding will be controlled by parameters of reinforcement. This correlation between differential responses and reinforcement is non-existent in single-response procedures (i.e., the correlation between responding and reinforcement magnitude is 1.0).

Neuringer (1967) has also commented on this topic:

Magnitude is a contingent dimension of reinforcement in many multi-operandum choice experiments; *e.g.*, one magnitude is obtained for a left choice and a different magnitude for a right choice. In most single-operandum experiments, magnitude is a non-contingent dimension, different magnitudes presented independently of the subject's behavior. (pp. 422 – 423)

However, the use of repeated-shift procedures has also produced a similarly inconsistent pattern in responding. For example, Dickson and Thomas (1963) trained pigeons in a multiple schedule in which the stimulus in each component (i.e., key light) was correlated with a particular duration of access to grain. Across conditions, Dickson and Thomas manipulated the duration of access to grain correlated with each key color such that different combinations of reinforcement durations could be compared. In some conditions the differential durations represented large, absolute differences (e.g., 10 s and 2 s) and in other conditions, differences were smaller, but measured in terms of the same relative durations (e.g., 5 s and 1 s). The alternative duration ranged from 83 percent to 0 percent longer than the shorter duration from which the relative response rates $[RPM_{Large} / (RPM_{Large} + RPM_{Small})]$ were hypothesized to correlate. However, in all conditions, severe undermatching (cf., Baum, 1979) was observed. As a direct example, when the relative duration of reinforcement was 0.833 for the experimental component, the relative response rate increased only by 0.08 from baseline (i.e., .50 to .58) when

that component was active. Even though severe undermatching was observed across conditions, it can be argued that changes in relative response rate did systematically correlate to changes in duration of reinforcement. However, and this is important to the current thesis, these changes reflect a less than proportional effect. Notably, a 33 percent increase in reinforcement duration resulted only in an approximately 8 percent change in behavior.

Catania (1963b) established the concurrent choice procedure as a reliable method for measuring the effects of differential reinforcement durations. Catania (1979) has further suggested that small effects of variables in single-response or multiple component schedules sometimes have large effects in concurrent schedules. A benefit of this method is that subjects are able to *repeatedly* contact – depending on the subject's allocation of responses – at least two durations of reinforcement, which may enhance discrimination and thus, better engender differential control of behavior by the duration of reinforcement (Kling & Schrier, 1971). However, even in choice paradigms, the effects of reinforcement duration are not simple or straightforward. For example, Walker, Schnelle, and Hurwitz (1970) presented simple concurrent VI schedules to rats in which responding on one lever was reinforced with a constant duration of access to a sucrose solution (1 s or 3 s, depending on group assignment) and responding on the alternative lever was reinforced with varying reinforcement durations (2 s – 5 s). The alternative duration was changed every six sessions. Similar to Catania (1963b) and Dickson and Thomas (1963), response rates to the constant choice varied inversely to the duration of reinforcement delivered at the alternative choice. However, and again similar to the mentioned studies, severe undermatching was observed between relative response rates and relative reinforcer duration. Walker and colleagues cited the frequent magnitude alteration to explain the undermatching.

Premack (1965, as cited in Ten Eyck, 1970), Ten Eyck (1970), Todorov (1973) and Schneider (1973) have suggested that the rate of reinforcement, even if held constant, can moderate the effects of consequence-duration. That is, the measured effects of altering reinforcement duration may be mediated by the selected schedule of reinforcement. Accordingly, studies have incorporated the concurrent-chains procedure to study this possibility (Autor, 1960). The concurrent-chains procedure is a common arrangement in that subjects' responses commit future behavior to a given alternative with specified reinforcement parameters (Rachlin & Green, 1972). Once an initial-link schedule has been fulfilled, a sole terminal-link stimulus is presented. Fulfillment of this link then produces reinforcement. A useful contribution of the chains procedure is that reinforcement parameters (e.g., rate and duration) can be manipulated in the terminal links removed from where behavior is recorded, in the initial links. Control by the manipulated variable in the terminal links is demonstrated by correlated changes in response patterns occurring in the initial links.

An initial investigation by Ten Eyck (1970) first demonstrated the effects of co-varying rate and duration of reinforcement, collectively referred to as reinforcement time (RT; Premack, 1965) and calculated from the product of rate (r) and the duration of reinforcement (d): $RT = r \times d$. In a concurrent-chains procedure, pigeons' responses in the initial links produced terminal links with either constant reinforcement duration and varying rates (Experiment 1), constant rates and varying reinforcement duration (Experiment 2), or co-varied rates and reinforcement duration (Experiment 3). For each experiment, an alternative's RT of say, 6 s (with respect to say, a constant RT of 3 s) may have been calculated from $2r \times 3d$, $1r \times 6d$, and $3r \times 2d$, respectively. Matching was measured for all subjects when manipulations were made exclusively to rate (Experiment 1) and to the co-varied product of rate and duration (Experiment 3). A correlated

change in the relative response rate was observed when the duration of reinforcement was exclusively manipulated (Experiment 2), but the effect was noticeably less robust. These results led some to conclude that duration of access to a consequence was a variable of unequal strength to rate of reinforcement (Todorov, 1973). For example, the effects observed in the initial links when a terminal link leads to 6 s of reinforcement once per minute is less robust than when a terminal link leads to 3 s of reinforcement twice per minute, even though each scenario's respective RT is 6 s. It can be hypothesized that the latter has a more robust effect because the altered rate contingency may represent a more discriminable change in magnitude. Other studies have found similar results when simultaneously manipulating rate and quantity of reinforcement. For example, Schneider (1973) found that a fixed quantity of reinforcement per unit of time on a choice alternative maintained faster responding in pigeons when delivered more frequently in small amounts than when delivered less frequently in large amounts.

In addition to the previously mentioned studies and their accompanying manipulations, other studies have sought to examine the effects of manipulating stimulus conditions associated with reinforcement. In work with pigeons, parameters of the hopper light – active during the reinforcement – are commonly manipulated. For example, Mariner and Thomas (1969) measured changes in pigeons' response rates in a multiple schedule, with components differing in the duration of reinforcement. Initially, pigeons were trained to peck on a multiple schedule in which a red key light was correlated with a relatively long duration of access to grain (e.g., 6 s) and a green key light was correlated with a relatively short duration of access to grain (e.g., 2 s). In the first condition, the only manipulated variable was the components' duration of reinforcement and the hopper light intensity remained constant regardless of the reinforcement interval. No differential response patterns were measured as a function of the components.

de Villiers (1977) commented on these results and stated that “this could represent either a problem of discrimination or a fundamental difference in the relationship between response strength and various reinforcement parameters” (p. 249). That is to say, response patterns may have been equivocal between components due to a hindrance in discriminating the duration of reinforcement associated with each component. It has been further suggested that this hindrance may be caused by a delayed opportunity to discriminate differential reinforcement inherently present in duration-based manipulations. For example, in reinforcement consisting of either 4 s or 2 s access to grain, a difference between reinforcement durations can only be discerned once 2 s have passed. Removing this delay may then serve to enhance the evocative effects of increasing reinforcement duration. Different hopper lights, correlated with different reinforcement, may serve this function as they are correlated with immediate opportunities to discriminate the currently active duration of reinforcement. In this regard, Catania (1979) has also suggested that “stimuli that accompany reinforcers [e.g., hopper lights] can be used to augment the effectiveness of those reinforcers” (p. 192).

Providing evidence for this hypothesis are the results of Mariner and Thomas’s (1969) second condition in which the hopper light was differentially illuminated dependent on the duration of access to grain: a bright hopper light correlated with 6 s and a dim hopper light with 2 s (counterbalanced across subjects). Altering these stimulus conditions correlated with the reinforcement duration reliably facilitated the effects of increasing the reinforcement duration as clear response rate differentiation was measured.

In lieu of the patterns discussed, it may be especially useful to recall Guttman’s (1953) seminal comment regarding the reinforcing agent: “[Experimental] methods and results invite a reconceptualization of the reinforcing agent in such a manner that it can be explicitly treated as a

stimulus; whose effects depend on the procedural and methodological variations” (p. 222). Thus, two important components surface as foundational to determining the effect of manipulating a reinforcer’s duration: (a) the relative duration of a reinforcer (e.g., Catania, 1963b); and (b) the extent to which that duration is distinguishable from other durations (e.g., Mariner & Thomas, 1969).

As mentioned at the onset, duration-based manipulations only account for a portion of the methods used to manipulate magnitude. With regard to the discriminability of reinforcement magnitude similar themes have also surfaced in quantity- and volume-based studies. For example, Grindley (1929) and Wolf and Kaplon (1940) demonstrated that behavior was better maintained when reinforcement was presented as many, small reinforcers as to opposed a single, large reinforcer. Presumably, this occurred because the method of reinforcement facilitated an immediate opportunity for the discrimination of reinforcement magnitude. That is, many, small pieces *look* immediately different than one, large piece. Thus, immediate discrimination is possible. In contrast, a singular, large piece may require some amount of consummatory activity to determine any difference. Thus, an occasion for discrimination is presumably delayed.

If experimental parameters can be adjusted so as to reduce the confounding factors of delayed discrimination associated with altering reinforcement, might experiments better capture the *true* effects of increasing reinforcement duration? This is an empirical question and thus, is one of the primary purposes of the current study.

Current Study

de Villiers (1977) has suggested that in concurrent paradigms, “pigeons might match relative reinforcement durations more closely if differential signals were provided for the hopper duration” (p. 249). However, to date, no research has investigated the effect of duration of

reinforcement on preference using both a choice procedure and manipulations of the stimulus conditions correlated with reinforcement. To this end, the present research used pigeons as subjects and the concurrent-chains choice procedure. One terminal link led to a fixed duration of reinforcement (e.g., 3 s) correlated with a white hopper light. The other terminal link led across conditions to a longer duration of reinforcement (e.g., 6 s). In some conditions the longer duration of reinforcement was correlated with a hopper light of a different color (e.g., red or green). The hopper lights correlated with the duration of reinforcement can be referred to as duration-correlated stimuli (DCS).

Although several prior studies have utilized differential hopper illumination and reinforcement duration for studying the effects of reinforcement magnitude, the present study is unique in that the procedure uses a concurrent-chains choice paradigm and the measured behavior is preference. Thus, the present study seeks to examine the extent to which the pigeons will prefer the longer duration of reinforcement when both hopper lights are white, and then whether the pigeons will prefer the longer duration of reinforcement to a greater degree when it was correlated with a hopper light of a different color.

Method

Subjects

Three pigeons, designated P-140, P-141, and P-510, were maintained at approximately 80% ($\pm 5\%$) of their *ad libitum* weight throughout the duration of the experiment. The pigeons were approximately 4.5 years old, of mixed breeds, and had varying experimental histories. The pigeons were recently used in an experiment with similar methods (Weingarten, 2013). During the study, the pigeons had free access to water and grit in their respective home cages – located

in an adjacent laboratory with a 16-hours-on, 8-hours-off light cycle. Supplemental feedings were administered as necessary to maintain an appropriate weight.

Apparatus

Two standard operant chambers were used. The dimensions of one chamber were: 30 cm x 29 cm x 30 cm, and of the other: 30 cm x 48 cm x 36 cm. Both chambers had an integrated ventilation system that served to mask background noise. The chambers contained an intelligence panel with two circular pecking keys, positioned approximately 24 cm above the chamber floor. Keys could be illuminated by white, red, or green 28 vDC lights.

Also located on the intelligence panel was a rectangular opening – 5 cm x 6 cm, approximately 12 cm from the floor – that allowed pigeons to access grain from an elevated food hopper. The hopper was operated by a standard solenoid mechanism. Depending on the chamber, white, red, or green hopper lights could be used to illuminate the rectangular opening when the feeder was elevated.

Electrical-mechanical equipment in an adjacent room controlled experimental events and recorded the data.

Procedure

This experiment used the two-key concurrent-chains choice procedure, as described in Ten Eyck's (1970) Experiment 2.

Experimental sessions began with both keys illuminated white in an otherwise dark chamber. These keys represented the initial links in which concurrent VI 60 s schedules were in effect: 12 intervals made up each schedule. Responses on these keys that satisfied the initial link of the chain produced a change in key illumination by activating either a red (left) or green (right) light behind the key signaling the active terminal link, while the other key went dark and inoperative. A single timer arranged each transition to a terminal link ($p = 0.50$). Each terminal

link consisted of a VI 30 s schedule: two sequences of 12 intervals made up each terminal-link schedule. The intervals used in all schedules were calculated using the equations established by Fleshler and Hoffman (1962). When the terminal link schedule was satisfied, the terminal-link key went dark and the feeder was elevated and illuminated for a specific duration and allowed access to grain.

The reinforcement duration varied depending on the condition in effect. One alternative – termed the control choice – consistently led to 3 s access to grain, delivered under a white hopper light. The other alternative – termed the experimental choice – led to either 3 s or 6 s access to grain, delivered under a white or colored hopper light (red for P-510 and green for P-140 and P-141). The longer reinforcement duration (i.e., 6 s) was employed based on the findings of existing literature (e.g., Epstein, 1981; Epstein, 1985). Figure 1 presents a schematic of the experimental procedures.

Table 1 identifies the five experimental conditions and describes the parameters of the reinforcement for both terminal links. The conditions are labeled in Table 1 by combining a descriptor that first compares the duration of reinforcement between the control and experimental choice: “Equal” or “Unequal.” The second descriptor compares the hopper lights parameters (i.e., DCS) between the control and experimental choice: “Uncued” or “Cued.” Thus, the combined condition names are: Equal-Uncued, Unequal-Uncued, Equal-Cued, and Unequal-Cued.

Within each condition, at least three key reversal components – consisting of at least 15 sessions each – were implemented to ensure control by the relevant manipulations and not by key location. During the course of the experiment, the use of intervening schedules was occasionally necessary to return response allocation ratios to 0.5 (± 0.05) prior to reversal

components or conditions. On average, approximately 3 sessions of intervening schedules were necessary to return response allocation ratios to 0.5 (± 0.05).

Experimental conditions were conducted at least six days per week. Sessions ended after a fixed number of reinforcers (amounts varied from subject-to-subject to control for weight). Each experimental condition was in effect until stable response patterns were measured. A conservative steady-state stability criterion was used. This consisted of a minimum of 15 sessions in each condition. From the last nine sessions, the preference ratios (see Equation 1) were calculated and averaged over blocks of three sessions each. Responding was considered to be stable when two criteria were satisfied: (a) the means of the three blocks did not evidence either a monotonically increasing or decreasing trend; and (b) the maximum difference between block means was no greater than 0.05. When stability was attained, the average preference ratio from the three blocks was used as a measure of preference for the condition.

(1)

$$\text{Preference}_A = \frac{R_A}{R_A + R_B}$$

In Equation 1, the total number of initial-link responses on a key (R_A) is divided by the sum of the total initial-link responses ($R_A + R_B$).

The independent variables were the reinforcement duration and accompanying hopper light parameters and the dependent variable was the initial-link response allocation ratio.

Results

Figure 2 shows the preference ratios in the initial links under the five experimental conditions. Data are the mean preference ratios for the experimental alternative in each condition. The mean values were calculated once the established stability criteria were met. In all, 27 data

points were used to calculate each mean (i.e., last 9 experimental sessions x 3 reversal components).

The relative reinforcement durations for the experimental choice in the terminal link were 0.50, 0.67, 0.50, 0.67, and 0.67 for the five conditions, respectively. Changes in preference to the experimental choice tended to positively correlate with changes in the experimental duration of reinforcement however, the increases in preference consistently remained within the range of indifference when the longer duration of reinforcement was uncued.

When the relative reinforcement duration was 0.50 (i.e., Equal-Uncued & Equal-Cued), all three subjects responded at a level of indifference during the initial links ($\text{pref.} = 0.50 \pm 0.05$). When the relative reinforcement duration was 0.67 and differential hopper lights were *not* used (i.e., Unequal-Uncued), the preference ratios did increase slightly. However, for subjects P-140 and P-141, the increase in preference was still within the range of indifference for both presentations of the Unequal-Uncued ($M_{\text{P-140}} = 0.528$ & 0.543 ; $M_{\text{P-141}} = 0.515$ & 0.50). Subject P-510, on the other hand, preferred the experimental key during the first Unequal-Uncued condition ($M = 0.568$), but not during the second Unequal-Uncued condition ($M = 0.546$). During the critical condition, in which the relative reinforcement duration was 0.67 and differential hopper lights *were* used (i.e., Unequal-Cued), all three subjects preferred the experimental key ($M_{\text{P-140}} = 0.574$, $M_{\text{P-141}} = 0.591$, $M_{\text{P-510}} = 0.624$).

Secondary to the above results was the finding that, in general, when the relative reinforcement duration was 0.67 and differential hopper lights were used (i.e., Unequal-Cued), variability in responding between reversal components decreased substantially. Table 2 shows mean preference ratios across the three key reversal components for each condition. As can be seen in the table, the reversal means more closely approximate the overall condition mean in the

Unequal-Cued condition as compared to the Unequal-Uncued conditions. This pattern was especially prevalent in subjects P-140 and P-510, and to a lesser degree with subject P-141. For subjects P-140 and P-510, the reversal means in the Unequal-Cued condition deviated in absolute terms from the overall mean on average by 0.008 and 0.025, respectively. Across the two Unequal-Uncued conditions, the reversal means deviated on average by 0.064 and 0.044 for subject P-140 and P-510, respectively.

Discussion

The results from the present study provide empirical evidence for the suggestion that the different stimuli accompanying the different hopper durations enhance choice responding by eliminating or diminishing the inhibitory effects of delayed reinforcement discrimination. Subjects consistently responded preferentially to the experimental key in the initial links when a different colored hopper light accompanied the increased reinforcement duration for that choice (i.e., Unequal-Cued). During the mentioned critical condition, P-510 most closely approximated perfect matching in the initial links between relative response allocation and relative reinforcement duration. Though the relative response allocation ratios of P-140 and P-141 remained somewhat distant from what was expected based on the relative reinforcement duration in the Unequal-Cued condition, the mean preference ratios were still exceptionally higher (in some cases, *significantly* higher, see Table 3) compared to the averages of the Unequal-Uncued condition. We can assert with some confidence that the different colored hopper lights did not elicit increased responding independently of the reinforcement duration, as the subjects responded at a level of indifference in both conditions with relative reinforcement durations of 0.50 and there was no apparent difference between the means of the Equal-Uncued condition and the Equal-Cued condition. Taken together, the above results provide support for de Villier's

(1977) suggestion and the interpretation offered by Catania (1979) concerning the augmentative effects of different colored hopper lights specific to the different durations of reinforcement. The hopper light served the function of providing an *immediate* stimulus for the subject to discriminate the duration of reinforcement. This engendered better control over responding by the relative reinforcement duration. Other studies have also found that preference can be affected by the acquired conditioned reinforcement of signaling reinforcement parameters (e.g., Colton & Moore, 1997).

Another interesting finding from the current study was the decreased variability between the three means of the reversal components in the Unequal-Cued condition compared to the Unequal-Uncued conditions. The different colored hopper lights enhanced the relatively rapid discrimination of the change in reinforcement contingencies when a key reversal went into effect. On average, reversal components lasted 15 sessions and once stability criteria were met, the reversal mean was calculated from the last nine sessions. The close proximity of the reversal means around the overall condition mean leads to the conclusion that preference ratios of the last nine sessions were also close to each other. Thus, after approximately six sessions in which new or reversed reinforcement contingencies were introduced, subjects had acquired a relatively stable preference ratio. The increased variability observed in Unequal-Uncued conditions indicates that many more reversals would have been necessary per each condition to obtain similar results to those observed in the Unequal-Cued condition.

The results and conclusions of the current study differ to some degree from those in Ten Eyck (1970). Namely, Ten Eyck reported that pigeons' relative rate of responding approximated the relative reinforcement duration *without the use of* different colored hopper lights. The observation that pigeons prefer longer durations of reinforcement in concurrent choice

procedures has been reported elsewhere as well (e.g., Grace & McLean, 2015). In the current study however, a similar effect was not observed to the same degree and consistency. In view of these contrasting findings, it is important to note at least one methodological difference between the current study and such others as Ten Eyck.

The methodological difference is that the current study included within condition key reversals, whereas Ten Eyck (1970) did not. Thus, the current study examined the effect of reinforcement duration and/or hopper light color first in one terminal link, then in the other. Conditions were in effect until responding stabilized before being reversed with respect to the terminal links. In contrast, Ten Eyck arranged for the longer duration of reinforcement to always appear on the left terminal-link key. Perhaps Ten Eyck's results are an artificially inflated measure of preference, in that the longer duration of reinforcement was always on the same terminal-link key. In contrast, a discrimination and reversal has generally come to be regarded as a suitable assessment of behavioral control (e.g., Autor, 1960; Herrnstein, 1964), and was therefore employed in the current study.

In the same line of reasoning however, that we *did* observe a significant effect in the Unequal-Cued condition supports the conclusion that different colored hopper lights augmented the effectiveness of reinforcement (Catania, 1979). The average preference ratio across the three subjects in the Unequal-Cued condition was 0.59. This is slightly less than the average relative response rate observed in the same condition in Ten Eyck's (1970) study, 0.61. As can be seen in Table 2, the pigeons were able to acquire the 0.59 level of preference after just 15 sessions per reversal in our critical condition. The different colored hopper lights enhanced the discrimination of the relative reinforcement duration in roughly one-third of the sessions and resulted in the quick acquisition of preference for the experimental choice.

Similar effects were measured in Mariner and Thomas (1969). In a multiple component procedure in which one component led to 2 s of reinforcement (C_1) and a second component led to 6 s of reinforcement (C_2), response rates to the C_2 only increased when hopper light intensity correlated with reinforcement duration. Further, when the hopper light intensity correlated with reinforcement duration, an increase in response rate to C_2 was observed after just five sessions. Though the current study differed methodologically in several areas, the function of the hopper lights paralleled the findings in Mariner and Thomas's initial study: Responding increased when hopper lights were correlated with increased reinforcement durations. Based on these findings, when different durations of reinforcement are made contingently available to pigeons in multi-operandum experiments (Neuringer, 1967) and a magnitude effect is sought, it seems to be an arbitrary choice as to whether different *colored* hopper lights or difference hopper light *intensities* should be used. In theory, this would be true as long as the intensities or colors are detectably different from one another. Thus, the key parameter seems to be the correlated activation of an exteroceptive stimulus specific to a given duration of reinforcement. However, empirical evidence might measure differential levels of effectiveness of accompanying stimuli (e.g., lights, tones, etc.). Future research may also find that the effectiveness of correlated stimuli interact with other variables in the experiment (e.g., procedure, species of subject, absolute reinforcement durations).

In lieu of the current study's findings, several limitations need to be discussed. First, we did not measure any within session data detailing cycle-by-cycle changes in preference. Data of this sort might be important in the study of choice and reinforcement variables. For example, Kyonka (2008) observed preference reversals in pigeons within a single session for alternatives that were correlated with a richer rate and larger magnitude of reinforcement even after stable

responding had been acquired for the other choice in a concurrent operants procedure. Kyonka and Grace (2008) also found that relative response allocation in a concurrent-chains procedure was best predicted from within session variables and not the number of session exposures. The mentioned within session response patterns would not have been observable if data were collected and averaged at the end of an experimental session. Other researchers have also suggested the inclusion of within session data to complement other measures of behavior (e.g., Beeby & White, 2013). With respect to the current study's procedure, future research may find this data useful if an evaluation of the efficiency of the manipulation is sought. On this note, Baron and Herpolsheimer (1999) have further discussed the use of within session data as a means to ameliorate non-normal distributions. In line with this, the current study did detect positive skews in the session-by-session mean preference ratios throughout the Unequal conditions. This is evident by examining the differences in the means and medians for each condition (see Table 4).

A second limitation of the current study is that we did not record the amount of grain consumed by pigeons. Epstein (1981) has noted a non-linear relationship between the duration of the reinforcement and the amount consumed when a two-piece (e.g., Gerbrands Model B) feeding magazine was used. Epstein (1985) then later demonstrated that the consumption curve was actually dependent on the type of feeder used: When a one-piece (e.g., Lehigh Valley Model A) magazine was used, grain consumption was linearly correlated to reinforcement duration. In the current study, one chamber was equipped with a two-piece magazine and one chamber was equipped with a one-piece magazine. Thus, it is possible that the amount of grain consumed was not a stable variable across the subjects. The significance of this difference was minimized as the duration of reinforcement remained under 8 s – a duration that was linearly correlated to grain

consumption independent of the feeder design. However, it is rather interesting that the chamber with the one-piece magazine was used for the subject (P-510) that recorded the highest mean preference to the experimental key during the Unequal conditions (see Figure 3). This may just represent an interesting coincidence, but future research may benefit from data on the amount of a reinforcer consumed, especially as it relates to preference. For example, the amount of grain consumed could be determined by the difference of grain contained in the food hopper following a session compared to its level at the start of the session. The amount consumed per cycle could then be calculated by dividing the difference in levels of grain by the number of reinforcement cycles resulting in the *grain consumed per reinforcement cycle*. An interesting avenue of research would then be the analysis of how the preceding values on consumption covary with preference and then, the dependency of that relationship on the experimental manipulations mentioned in the present study.

In conclusion, the findings of this study found that initial link preference most closely approximated relative reinforcement durations of 0.67 when duration-correlated stimuli – different colored hopper lights – accompanied the delivery of reinforcement in the terminal links. Because of the current study's experimental design, we can assert that the stimuli functioned as a discriminative stimulus to immediately signal to the subject the activated duration of reinforcement. Not only did the use of these stimuli more reliably predict preference, but their inclusion also coincided with substantial decreases in the variability of response allocation within conditions. Thus, as it concerns the suggestions put forth by de Villiers (1977), the present research joins Mariner and Thomas (1969) in showing that stimuli can alter the effectiveness of a reinforcer when correlated to the delivery of reinforcement (Catania, 1979).

Figure 1.

Concurrent-chains and differential reinforcement duration.

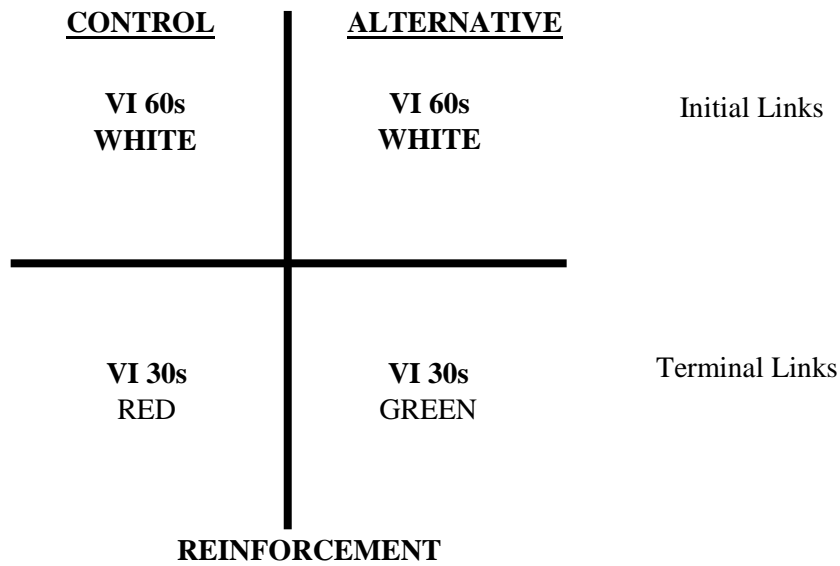


Figure 1. The parameters of reinforcement following completion of the terminal links are determined based on the condition in effect (see Table 1). The colors below the reinforcement schedules in the initial and terminal links refers to the hue of the key light.

Figure 2.

Preference ratios for the experimental key across conditions.

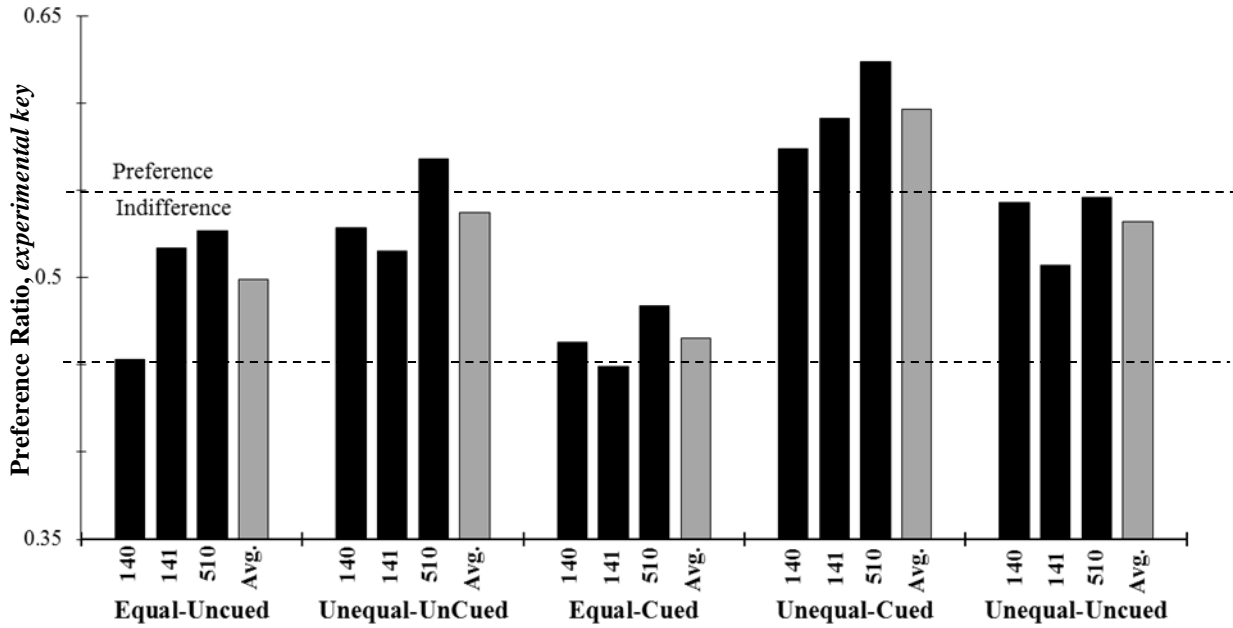


Figure 2: Condition names are abbreviated based on the comparisons detailed in Table 1. The black bars measure the level of preference to the experimental key during the initial links for each subject; grey bars measure the average preference across subjects per each condition. The dashed lines on the graph identify the range of indifference (pref. = 0.50 ± 0.05).

Figure 3.

Preference in the Unequal conditions as a function of feeder design.

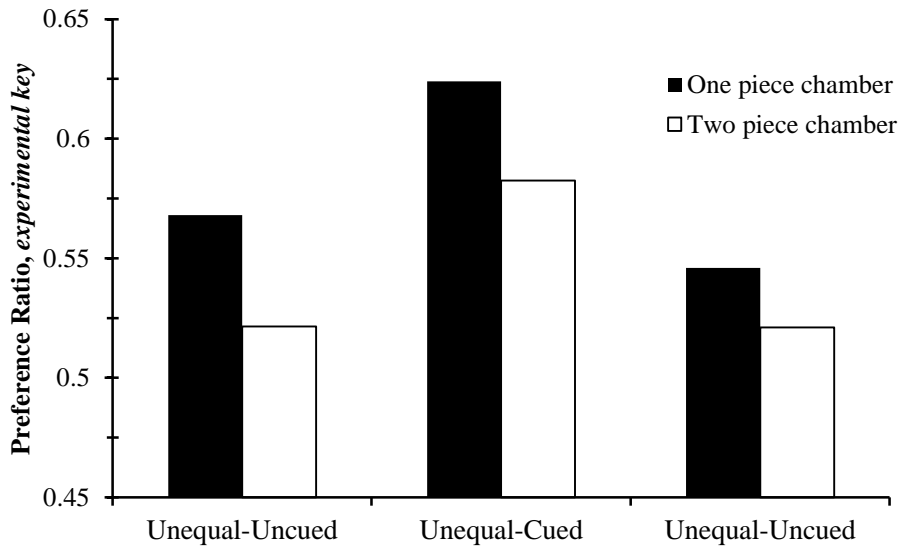


Figure 3: Average preference ratios across the three Unequal conditions are graphed as a function of the feeder design. P-140 and P-141 completed sessions in a chamber with the two piece feeder (white bars) and P-510 completed sessions in a chamber with the one piece feeder (black bars).

Table 1.

Summary of reinforcement parameters across conditions.

Condition	Control Terminal Link		Alternative Terminal Link	
	Rft. Duration (s)	Hopper Light	Rft. Duration (s)	Hopper Light
Equal-Uncued	3	White	3	White
Unequal-Uncued	3	W	6	W
Equal-Cued	3	W	3	Red
Unequal-Cued	3	W	6	R
Unequal-Uncued	3	W	6	W

Table 1. The name of each condition describes comparisons of reinforcement duration between the control and alternative choices (i.e., *Equal* or *Unequal*) and whether or not the reinforcement duration is cued via a differential hopper light (i.e., *Cued* or *Uncued*).

Table 2.*Preference ratios of within-condition reversal components.*

Subject	Reversal	Equal-Uncued	Unequal-Uncued	Equal-Cued	Unequal-Cued	Unequal-Uncued
P-140	1	0.403	0.384	0.520	0.562	0.590
	2	0.453	0.589	0.425	0.582	0.520
	3	0.502	0.612	0.445	0.579	0.518
	Avg.	0.453	0.528	0.463	0.574	0.542
	SD	(0.061)	(0.113)	(0.050)	(0.033)	(0.053)
		<i>45</i>	<i>48</i>	<i>45</i>	<i>45</i>	<i>45</i>
P-141	1	0.532	0.422	0.468	0.655	0.491
	2	0.513	0.457	0.417	0.526	0.504
	3	0.507	0.667	0.461	0.592	0.507
	Avg.	0.517	0.515	0.449	0.591	0.500
	SD	(0.073)	(0.112)	(0.051)	(0.061)	(0.030)
		<i>46</i>	<i>58</i>	<i>51</i>	<i>47</i>	<i>45</i>
P-510	1	0.591	0.486	0.501	0.636	0.569
	2	0.491	0.625	0.480	0.587	0.497
	3	0.498	0.594	0.470	0.649	0.573
	Avg.	0.527	0.568	0.484	0.624	0.546
	SD	(0.106)	(0.074)	(0.037)	(0.068)	(0.051)
		<i>45</i>	<i>48</i>	<i>45</i>	<i>45</i>	<i>45</i>
Avg.	1	0.509	0.431	0.496	0.618	0.550
	2	0.486	0.557	0.441	0.565	0.507
	3	0.502	0.624	0.459	0.607	0.533
	Avg.	0.499	0.537	0.465	0.596	0.530

Table 2: For each subject, the preference ratios are measured for each reversal within a given session. Bold preference ratios identify the overall condition average. The standard deviation for each condition is notated in parentheses next to the condition mean. The italic numbers below each condition mean identify the total number of sessions necessary to satisfy the stability criteria. The standard deviations and number of sessions to stability are not reported for the overall average across subjects as those values would measure between-subject variability.

Table 3.*Statistical post hoc comparisons between conditions.*

Subject		Unequal-Uncued	Equal-Cued	Unequal-Cued	Unequal-Uncued
P-140	Equal-Uncued	-0.076*	-0.009	-0.122*	-0.090*
	Unequal-Uncued		0.066	-0.046	-0.015
	Equal-Cued			-0.113*	-0.081*
	Unequal-Cued				0.032
		Unequal-Uncued	Equal-Cued	Unequal-Cued	Unequal-Uncued
P-141	Equal-Uncued	-0.015	0.062*	-0.078*	0.010
	Unequal-Uncued		0.077*	-0.063	0.025
	Equal-Cued			-0.140*	0.052*
	Unequal-Cued				0.088*
		Unequal-Uncued	Equal-Cued	Unequal-Cued	Unequal-Uncued
P-510	Equal-Uncued	-0.011	0.076*	-0.060	0.013
	Unequal-Uncued		0.087*	-0.049	0.024
	Equal-Cued			-0.136*	-0.063*
	Unequal-Cued				0.073*

Table 3. The differences in means are reported for each condition with respect to the vertical column (vertical column – horizontal row). The significance (p -value) of the t -statistics is based on the Bonferroni alpha correction procedure ($\alpha_{\text{pairwise}} = \frac{0.05}{10}$). Significant comparisons are marked with an asterisk (*). Post hoc comparisons were made following one-way repeated-measures analyses of variance (ANOVA) of the condition means for each subject. Redundant and same-condition comparisons are omitted from the table.

Table 4.*Condition mean and median comparisons.*

Subject		Equal-Uncued	Unequal-Uncued	Equal-Cued	Unequal-Cued	Unequal-Uncued
P-140	Mean	0.453	0.528	0.463	0.574	0.542
	Median	0.454	0.574	0.462	0.575	0.523
P-141	Mean	0.517	0.515	0.449	0.591	0.500
	Median	0.509	0.482	0.453	0.588	0.497
P-510	Mean	0.527	0.568	0.484	0.624	0.546
	Median	0.508	0.578	0.483	0.617	0.548

Table 4. The condition mean and median preference ratios across conditions are presented for each subject. When the median is higher than the mean, the distribution of preference ratios is negatively skewed. When the mean is higher than the median, the distribution of preference ratios is positively skewed. Where the mean and median are equal (± 0.05) a normal distribution of preference ratios can be assumed.

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