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Choice, Conditioned Reinforcement, and the Prius Effect

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Psychologists have long been intrigued with the rationales that underlie our decisions. Similarly, the concept of conditioned reinforcement has a venerable history, particularly in accounting for behavior not obviously maintained by primary reinforcers. The studies of choice and of conditioned reinforcement have often developed in lockstep. Many contemporary approaches to these fundamental topics share an emphasis on context and on relative value. We trace the evolution of thinking about the potency of conditioned reinforcers from stimuli that were thought to acquire their value from pairings with more fundamental reinforcers to stimuli that acquire their value by being differentially correlated with these more fundamental reinforcers. We discuss some seminal experiments (including several that have been underappreciated) and some ongoing data, all of which have propelled us to the conclusion that the strength of conditioned reinforcers is determined by their signaling a relative improvement in the organism's relation to reinforcement.

Key words: choice, conditioned reinforcement, delay-reduction theory, observing, matching law, chain schedules, context

In the 1960s conditioned reinforcement was a topic that was considered central to an understanding of behavior. Indeed, especially when human behavior was involved, most behavior whose maintenance could not be attributed to primary reinforcement was explained in terms of conditioned reinforcement. At least two influential books on the subject were published in the 1960s (Hendry, 1969; Wike, 1966). It was thought that by pairing a stimulus with a primary reinforcer, that stimulus would acquire reinforcing power and would itself be able to maintain behavior. Because most behavior was not obviously maintained by established primary reinforcers there appeared to be a large role for conditioned reinforcement in the maintenance of behavior (human behavior in particular).

At the same time, it was becoming clear that our understanding of conditioned reinforcement was incomplete at best. In this paper I will review some landmark studies that helped set the record straight on conditioned reinforcement. That several of these studies were ignored or unpublished is a testimony to the proposition that results at odds with the current Zeitgeist tend to be given short shrift. In other words, these studies are "landmarks" in retrospect only. Together with some more contemporary studies, they help to define for us the current status of conditioned reinforcement and especially its relation to choice.

GOLLUB'S THESIS ON EXTENDED-CHAIN SCHEDULES

The first study, a favorite of mine, was Lewis Gollub's doctoral dissertation at Harvard (Gollub, 1958). He studied the maintenance of key pecking by pigeons on extended chain and tandem schedules. In both types of schedules, the requirement specified

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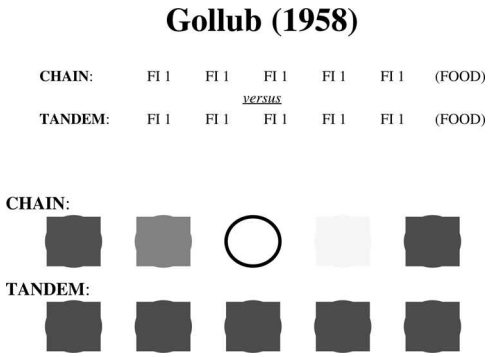

Figure 1. The procedure in Gollub's (1958) classic study. In the comparison shown above, the behavior of pigeons was compared on extended (here, five-link) chain and tandem schedules. In the chain schedule a different light is associated with each link of the chain. In the tandem schedule, however, although the response requirements are identical to those of the chain, the same stimulus is present throughout the schedule.

by each link of the schedule must be satisfied before the pigeon can advance to the next link. The tandem serves as a control for the chain in that it has the identical response requirement. On the chain schedule, however, each of the two or more links is associated with a unique discriminative stimulus (usually a key light), whereas the same discriminative stimulus is present throughout the tandem schedule. Thus any conditioned reinforcing properties of the stimuli making up the chain schedule may be assessed by comparing the rates and patterns of responding on comparable chain and tandem schedules. Figure 1 depicts one of the comparisons from Gollub's work, five-link chain and tandem schedules with fixed-interval (FI) 1-min components. To produce food reinforcement, the pigeon had to respond once after the first FI 1 timed out in order to move on to the second, and so on; the first peck after the fifth FI 1 timed out produced food.

I spend a class period on this study every year in my learning and motivation course at the University of California, San Diego (UCSD). After presenting the schedules shown in Figure 1, I ask students which of the schedules—tandem or chain—will better maintain behavior in the sense of higher rates of responding and more rapid production of primary reinforcement. Well over 90% of my students opt for the chain schedule. They argue persuasively that the chain is laden with conditioned reinforcement (obtained each time a new link is gained) as well as information and discriminative stimuli that let the pigeon in on its progress. Rarely does a student note that the stimulus present throughout the tandem schedule is one that is directly paired with food. The results from Gollub's pigeons thus surprise the students. Not only does the tandem schedule maintain responding better than does the chain schedule, but the pigeons typically come to stop responding altogether in the initial link of the chain. Nor do they improve on the schedule. In fact, as they come under better stimulus control, their response rates on the chain schedule eventually move to zero (more details are available in Fantino & Logan, 1979, p. 183, and, of course, in Gollub, 1958). Fantino (1969b) obtained similar results with rats. In that study, Kurt Fischer (an undergraduate at Yale University at the time) and I tried what we thought were a variety of innovations to encourage the rats to respond in the early links of the chain. Almost anything novel worked for a time until the rats' lever pressing came under stimulus control and responding ceased altogether. One of our innovations involved making the chamber so small that pressing the lever would have appeared to be the only convenient behavior available to our rats. However, the rats instead managed to adopt a posture facing away from the lever. Thus, it appears as if the organism comes under stimulus control and stops responding because the stimuli present during the early links of extended chain schedules are correlated with (are

cues for) nonreinforcement. In other words, the early stimuli in the chain tell the organism that it is far from reinforcement. Thus, these stimuli are not only not conditioned reinforcers, but they actually serve as cues for nonreinforcement and hence nonresponding.

I digress to an interesting corollary of Gollub's (1958) treatise. In his extended chain schedules, there is a stimulus that serves as a stimulus for responding in its presence (a discriminative stimulus) that fails to serve as a conditioned reinforcer maintaining responses in the prior link. The reverse may also be demonstrated, as in Fantino (1965). This was a choice study on pigeons' preference for variable versus comparable fixed schedules of reinforcement. Pigeons demonstrated a robust preference for the more variable reward. Preference was assessed in a standard concurrent-chains schedule, as depicted in Figure 2 (for the more typical case with variable-interval [VI] schedule outcomes). Pigeons chose on equal VI schedules in the initial links (choice phase); successful completion of either VI schedule produced entry into the corresponding terminal link (outcome phase) associated with either a fixed-ratio (FR) schedule (e.g., FR 50) or a mixed-ratio schedule (e.g., FR 1 or FR 99, each with a probability of .5). For our present purpose, the interesting data emerged when responding for food was placed on extinction. Now, when the pigeon entered the terminal link, successful completion of the ratio schedule led only to a return to the initial link (or choice phase), without encountering food. As shown in Figure 3, pigeons soon learned to stop pecking in the outcome phase. Yet they continued to respond robustly in the choice phase, thereby producing entry into the outcome phase. If the experimenter manually reset the program to the choice phase, the dormant pigeon would immediately resume a high rate of responding. Thus, the

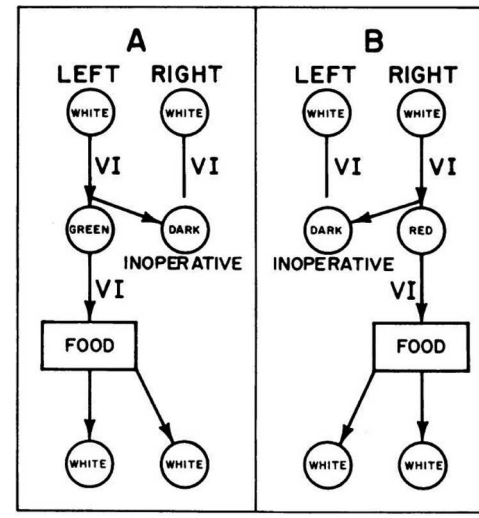

Figure 2. A standard concurrent-chains procedure. The left depicts the sequence of events when responses on the left key are reinforced, the right depicts the analogous sequence for the right key. Responses in the presence of the colored lights (the stimuli of the terminal links or outcome phase) are reinforced with food according to some schedule of reinforcement (generally the independent variable; in the figure these schedules are both VI schedules). The measure of choice is the relative rate of responding in the presence of the concurrently available white lights (the initial links or choice phase). Typically, equal VI schedules arrange access to the terminal links (but see Figure 6 for an exception). (After Fantino, 1969. Copyright 1969 by the Society for the Experimental Analysis of Behavior, Inc. Redrawn by permission)

terminal-link stimuli were no longer discriminative stimuli for responding in their presence, but they still maintained a robust rate of responding in the initial links. These disassociations between the discriminative and conditioned reinforcing functions of a stimulus are the exceptions to the rule that discriminative stimuli will serve as conditioned reinforcers, and vice versa (the discriminative stimulus hypothesis of conditioned reinforcement; Keller & Schoenfeld, 1950; Skinner, 1938).

This paper will emphasize a theme introduced now: We cannot infer that outcomes associated with robust rates of responding are preferred to

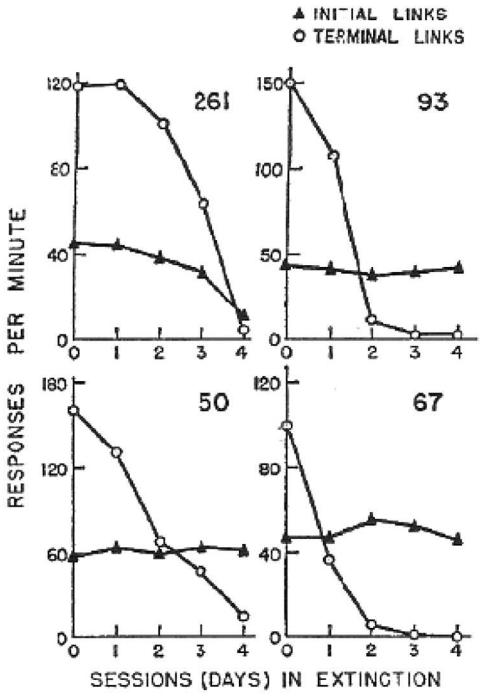

Figure 3. Rate of responding in both initial and terminal links for 4 pigeons in each of four sessions of extinction. Session 0 was the session prior to extinction. During extinction food was not presented on completion of the FR schedules, yet responding was maintained in the initial link by the stimulus correlated with the terminal link. (After Fantino, 1965)

those associated with lower rates of responding. What if pigeons were given the choice of responding on a chain or equivalent tandem schedule? Would they choose the tandem schedule, as might be surmised from Gollub's (1958) research? Or might they be indifferent to the outcomes because they are associated with equivalent rates of reinforcement (or to use a terminology taken up later, because they are associated with equivalent reductions in time to reward, or delay reduction)? Figure 4 shows the type of choice Duncan and Fantino (1972) gave their pigeons. Consistent with Gollub's results, pigeons displayed a striking preference for the tandem schedule.

Returning to the message of Gollub's (1958) study, with further support from the choice studies, the following conclusion seems to be warranted: Stimuli associated with the final link of the chain schedule (and throughout the tandem schedule) appear to be bona fide conditioned reinforcers, because they are directly paired with primary reinforcement. A powerful demonstration of this possibility comes from another classic study, that of Roger Kelleher (1966). Whereas in Gollub's study (and in my corresponding study with rats) subjects did not maintain responding even though, by responding, they could obtain a reinforcer every 5 min, Kelleher's pigeons responded at spirited rates on a schedule that provided a maximum of one reinforcer per hour. In Kelleher's study pigeons had to satisfy 15 consecutive FI 4-min schedules in order to obtain food. In the central condition the completion of each FI 4 schedule produced a flash of white light (0.7 s) that was also paired with the presentation of food after the 15th and final FI 4. Hence, this was a paired brief stimulus and an apparently potent conditioned reinforcer. The contrast between Gollub's results and Kelleher's is striking and points to the power of ostensibly minor changes in arranging stimulus presentations on behavior. The power of the brief-stimulus presentations to radically enhance rates of responding would certainly be consistent with the effectiveness of paired stimuli in animal training acts, including the effectiveness of tokens and clicker training. At this point in our story the message appears to be clear: Conditioned reinforcers are those that are paired directly to primary reinforcers. This message is consistent with the prevailing view of conditioned reinforcement at that time, namely, the pairing hypothesis of conditioned reinforcement, which avers that stimuli acquire their conditioned reinforcing strength by virtue of simple (Pavlovian) pairing with primary reinforcement. But the next

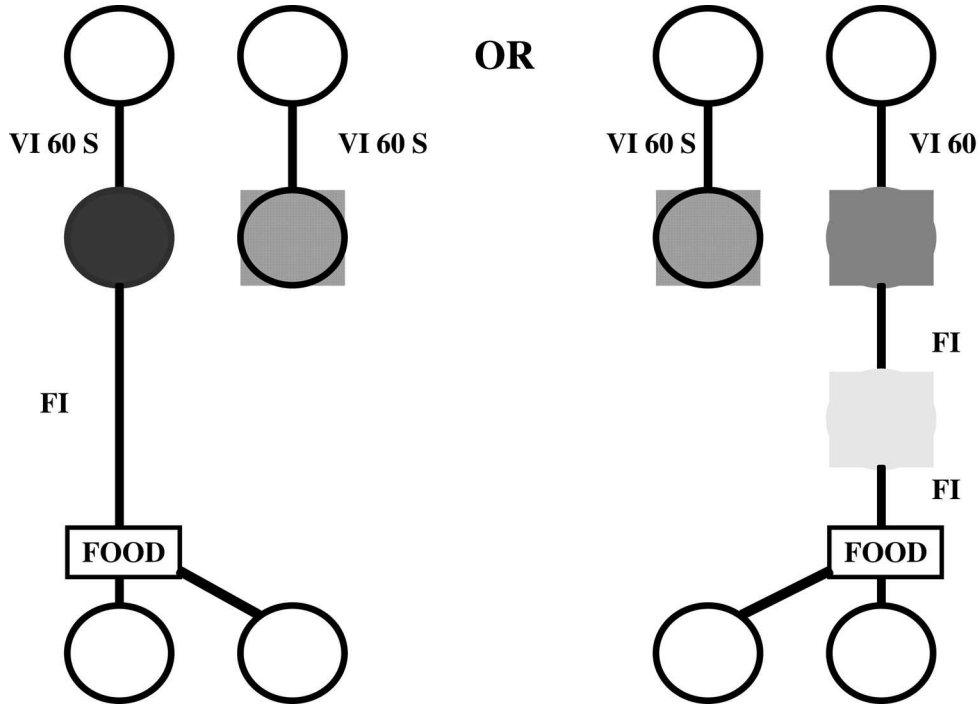

Figure 4. The experimental procedure used by Duncan and Fantino. The left portion indicates the sequence of events when responses on the left key were reinforced; the right portion indicates the sequence of events when responses on the right key were reinforced. The terminal links consisted of a simple FI 2*x*-s schedule on one of the keys and a chain FI *x*-s FI *x*-s schedule on the other key. (After Duncan & Fantino, 1972. Copyright 1972 by the Society for the Experimental Analysis of Behavior, Inc. Redrawn by permission)

sets of studies showed that the prevailing view was not tenable.

THE DISSERTATIONS OF RICHARD SCHUSTER AND NANCY SQUIRES

Richard Schuster, now at the University of Haifa, proposed an alternative or functional view of conditioned reinforcement. According to his functional view, the effects of an arbitrary stimulus that follows a response depend on the reinforcing consequences that are cued by the stimulus. In most experiments on conditioned reinforcement, the putative conditioned reinforcers are predictive of primary reinforcement, and both the traditional pairing hypothesis of conditioned reinforcement and the functional view make the same prediction: The stimulus should function as a conditioned reinforcer. However, Schuster (1969) conducted a series of experiments that teased apart the predictions of these views. He used a modified concurrent-chains procedure in which the initial links (choice phase) were equal VI 1-min schedules. The outcome on both terminal-link schedules (outcome phase) was a VI 30-s schedule of food reinforcement. The difference between the two terminal links was that in one terminal link, brief-stimulus presentations were available on a superimposed FR 11 schedule of reinforcement (see Figure 5). The brief stimuli were putative conditioned reinforcers in both the pairing and functional sense because they were paired with and signaled the availability of food reinforcement. This approach permitted two interesting questions:

1. If the paired brief stimuli were effective conditioned reinforcers, then they should have enhanced respond-

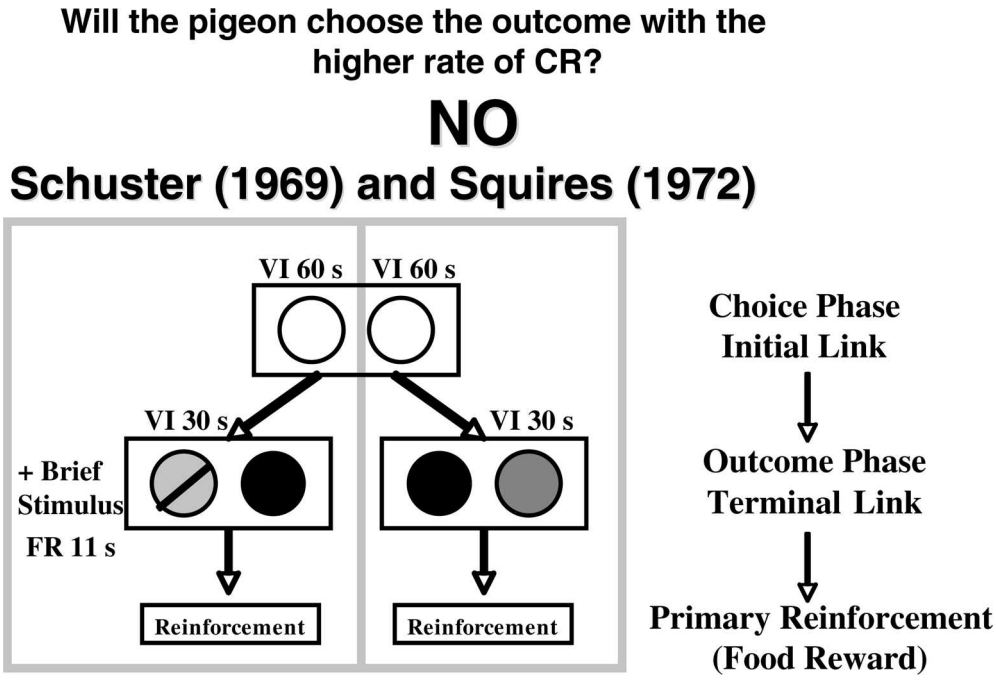

Figure 5. A schematic version of the basic experimental procedures used in the studies of Schuster (1969) and Squires (1972).

ing selectively on the terminal link in the outcome phase with the superimposed schedule of brief-stimulus presentations. Thus, were the rates of responding during the terminal link with the brief stimuli higher than on the otherwise equivalent terminal link without the brief stimuli?

2. Whatever the answer to the first question, was choice affected? In other words, was the initial link leading to the outcome with the superimposed conditioned reinforcement preferred to the initial link without the putative conditioned reinforcers?

According to the traditional pairing hypothesis of conditioned reinforcement, the answer to both questions should be "yes." The empirical answer to the first question was "yes," apparently establishing the paired brief stimuli as bona fide conditioned reinforcers. But this conditioned reinforcement effect was not accompanied by a concomitant preference for the conditioned reinforcement side. In other words, the answer to the second question was "no." In fact, just the reverse was observed: All 5 pigeons preferred the outcome without the superimposed conditioned reinforcers. The mean preference for the terminal-link side with the superimposed conditioned reinforcers was 0.39. Thus, these results flew in the face of the traditional pairing hypothesis of conditioned reinforcement.

Schuster's (1969) results were controversial. I know that I, for one, did not fully appreciate them. Nancy Squires (now at SUNY Stony Brook) did her dissertation at UCSD, further exploring the issues Schuster had raised. A potentially important change involved arranging the paired brief stimuli on interval schedules, thereby avoiding the high rates of responding generated by the FR 11 schedules used by Schuster (in the event that these high rates were paradoxically aversive, a possibility consistent with the results of Fantino,

1968; Moore & Fantino, 1975). Thus, in one terminal link of the concurrent-chains procedure used in Experiment A of Squires (1972), brief-stimulus presentations were arranged on a VI 15-s schedule. These stimuli also were paired with primary reinforcement. At the same time, responding on a VI 60-s schedule produced food in the same terminal link. Hence the schedule in one terminal link consisted of these two independent schedules (one for paired brief stimuli, the other for food). The other terminal-link schedule in Experiment A consisted of the food schedule only (also VI 60 s). Thus, as in Schuster's experiment, the two terminal-link outcomes differed only in the availability of the paired brief-stimulus presentations. Experiment B was analogous to Experiment A except that the brief stimuli were never paired with or signaled reinforcement; hence, these stimuli should not have served as conditioned reinforcers.

Squires (1972) found the same pattern of results in Experiments A and B despite the fact that the brief stimuli were paired in Experiment A but unpaired in Experiment B: No systematic initial-link (choice) preferences were found in either of the experiments. The aversion for paired brief stimuli found by Schuster (1969) did not occur in these experiments, presumably because the brief stimuli were arranged on interval rather than ratio schedules. However, the fundamental conclusion of Schuster's experiments was confirmed: outcomes with paired brief-stimulus presentations are not preferred to outcomes with either unpaired brief-stimulus presentations or to outcomes without brief-stimulus presentations. A review by Fantino and Romanowich (2007) provides a more complete discussion of these two landmark (yet often overlooked) dissertations. The review also discusses additional experiments (e.g., Fantino, Freed, Preston, & Williams, 1991) that support the conclusion that stimuli that behave as conditioned reinforcers in the outcome phase of concurrent-chains schedules do not appear to be conditioned reinforcers as measured by their influence on choice. That is, outcomes dispensing these stimuli are not chosen. We shall return to this central fact at the end of this paper. First, with this background, we move on to the quantitative study of choice and conditioned reinforcement.

QUANTITATIVE STUDY OF CHOICE AND CONDITIONED REINFORCEMENT

There is little need here to review the quantitative law of effect, more commonly known as the matching law, which asserts that organisms tend to distribute their choice responses according to the relative rate at which these responses are reinforced (Herrnstein, 1961). In other words, the distribution of choices tends to match the distribution of reinforcements. This law, which has proven to be a powerful predictor of behavior in a wide range of situations, has been refined and extended in important papers by Baum (1974), Catania (1963), Killeen (1972), Myers and Myers (1977), Rachlin and Green (1972), and others.

Autor (1960, 1969) and Herrnstein (1964) raised the possibility that the matching law may also describe choice in concurrent-chains schedules (Figure 2). If so, the matching law could be extended to describe choice for conditioned reinforcers; indeed, in elaborate studies, both Autor and Herrnstein varied the rates of primary reinforcement in the outcome phase of concurrent-chains schedules and measured the effects on the rates of responding in the choice phase. They both found that matching was obtained between the relative rates of responding in the choice phase and the relative rates of reinforcement in the outcome phase. If this finding

were generally valid, it would be a boon for simplicity: The same matching law would account for behavior maintained on simple concurrent schedules (by primary reinforcement) and on concurrent-chains schedules (by conditioned reinforcement). But this was too good to be true in terms of simplicity or parsimony. Moreover, there were reasons to be wary.

Modifying an example from Fantino and Logan (1979, p. 231), consider choosing between two favorite reinforcers, for example my wife's enticing hummus dip and her delightful beet and endive salad (the reader may substitute his or her own imaginary reinforcers, as long as they are both desired and one is slightly favored over the other). The two reinforcers are behind latched covers, each of which opens on a VI schedule. The response is turning a knob on each of the two covers. Suppose that the equal VI schedules arranging access to the outcomes (the foods) were short, say VI 10-s schedules. I maintain that you will respond almost exclusively on the knob leading to the preferred reinforcer (in my case the hummus) even though, owing to the nature of concurrent VI schedules, by responding on both you can cut your expected time to reinforcement in half (5 s instead of 10, on the average). This prediction is based on the assumption that you would probably be willing to expend a few extra seconds to assure that you obtain your slightly preferred reinforcer. On the other hand, what if the equal VI schedules were long in duration, say VI 1-hr schedules? Wouldn't you be more likely to respond on both knobs now (thereby obtaining a reinforcer every 30 min on the average), rather than to respond for 60 min exclusively on the knob leading to the slightly preferred reinforcer? More generally, the longer the choice duration, the more indifferent we may become to the two reinforcers. This intuition, if correct, has a profound implication for matching: Choice should not be invariant over variations in choice-phase duration. Matching should be expected only for a particular value of choice-phase duration. In fact, however, this intuition was not raised, and it first took some odd-looking data to challenge the notion that matching held in concurrent-chains schedules.

These data came from an experiment that sought to ascertain the relative contributions of conditioned and primary reinforcement to choice in a concurrent-chains schedule. In a typical concurrent-chains schedule, the VI schedules associated with the initial links (choice phase) are equal. But in this experiment the VI of the initial link on one key was VI 30 s leading to a VI 90-s outcome, and the VI of the initial link on the other key was VI 90 s leading to a VI 30-s outcome. Note that the overall time to primary reinforcement on each key is the same (120 s). If that is the central variable that controls choice, then the pigeon should be indifferent to the two options and should distribute its responses evenly to the two initial-link stimuli. On the other hand, if the rate of conditioned reinforcement is of paramount importance, then the pigeon should respond more to the stimulus associated with the VI 30-s initial-link schedule, because it produces entry into its terminal link at three times the rate as the corresponding VI 90-s initial link. A choice proportion of .75 might be anticipated if rate of conditioned reinforcement were the controlling variable. Finally, if rate of primary reinforcement in the outcome phase were the central determinant of choice, as postulated by the matching law (and as supported by the extensive data sets of Autor and Herrnstein), just the opposite result might be expected: a choice proportion of .75 for the VI 30-s outcome (i.e., pigeons should respond at three times the rate to the stimulus associated with the VI 90-s schedule leading to the VI 30-s outcome as to the

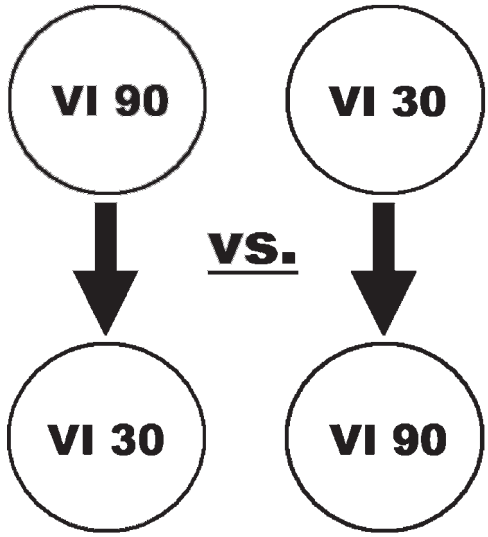

Figure 6. A schematic version of the basic experimental procedure used in the first condition of Fantino (1969a). Note that the schedules in both the initial and terminal links are unequal but that the sum of the schedule durations on each key both equal 120 s.

corresponding stimulus associated with the VI 30-s schedule leading to the VI 90-second outcome). Of course, both rates of conditioned and primary reinforcement might matter, in which case the choice proportions should lie somewhere between .50 and .75. The basic procedure is schematized in Figure 6. When I conducted this experiment (Fantino, 1969a) the early results were gratifying and appeared to resoundingly support matching (and an easy road to publication). Pigeons' preferences quickly gravitated to the VI 90-s initial link, as required by matching (with its emphasis on the rates of reinforcement in the outcome phase). But they did not reach .75 for that side and stop. Instead the preferences ballooned to around .90, inconsistent with all three theoretical possibilities outlines above. These results were food for thought.

The result of that thought was ultimately a rethinking of what might be the central variable critical for choice in a concurrent-chains schedule and to experiments that further tested the importance of this variable. The answer, of course, is simple with hindsight. Recall our example of hummus versus the beet and endive salad. There the temporal context helped to determine the degree of choice. Specifically, our intuition was that the longer the choice duration the less we would express preference for the slightly preferred of two reinforcers. Either outcome looked awfully good after a long bout of choice responding. Each represented a big change for the better. In the case of the VI outcomes, either outcome represented a large reduction in the expected time to reinforcement (delay reduction). Thus, there should not be so great a preference for the better outcome. With a short choice duration, however, only the preferred outcome represents a relatively large reduction in time to reinforcement and should therefore be more clearly preferred. To test this notion more directly, the duration of equal VI schedules was varied (from VI 40 s to VI 600 s) with VI 30-s and VI 90-s schedules in the outcome phase (Figure 7). As predicted, choice decreased dramatically as choice-phase duration increased (from exclusive preference for the VI 30-s outcome down to preferences approaching indifference). This result (Fantino, 1969a), replicated in many laboratories, has been called the initial-link effect and is predicted not only by delay-reduction theory (DRT) but also by more recent quantitative models of choice (including the contextual choice model of Grace, 1994, the incentive model of Killeen, 1982, and Killeen & Fantino, 1990, and the hyperbolic value-added model of Mazur, 2001; see Luco, 1990, and Preston & Fantino, 1991, for reviews).

This result is important because it shows that temporal context affects preference for conditioned reinforcement. Expressed differently, the strength of a stimulus as a conditioned reinforcer can be assessed only

$$\frac{R_L}{R_L + R_R} \begin{cases} = \dfrac{T - t_L}{(T - t_L) + (T - t_R)} & \text{when } t_L < T,\ t_R < T \\ = 1 & \text{when } t_L < T,\ t_R > T \\ = 0 & \text{when } t_L > T,\ t_R < T \end{cases}$$

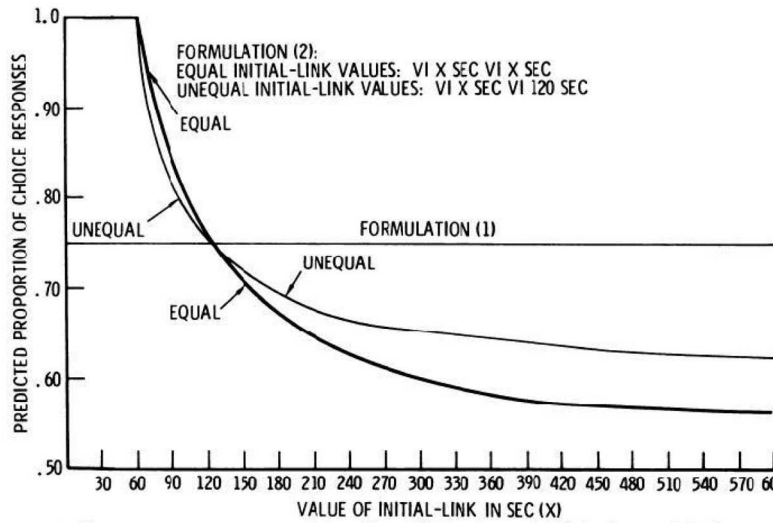

Figure 7. The top shows the original form of the delay-reduction formula, where T equals the time to food from the onset of a trial, and t_L and t_R denote the time to food remaining when the left or right terminal links are entered, respectively. Hence $T - t_L$ represents the reduction in time to reward associated with onset of the left terminal link, and $T - t_R$ represents the corresponding delay-reduction term for the onset of the right terminal link. The bottom shows that according to the matching law (Formulation 1), preference should not vary as the value of the initial link varies. However according to the delay-reduction equations, preference should vary dramatically as the initial-link duration (the duration of the choice phase) is varied.

by taking into account the relevant temporal context. In terms of DRT, the strength of a stimulus as a conditioned reinforcer is best predicted by the reduction in time to primary reinforcement correlated with the onset of the stimulus relative to the average time to reinforcement in the conditioning situation. A corollary of this finding is another blow to the traditional pairing hypothesis of conditioned reinforcement. For example, the results of Fantino (1969a) show that the same stimulus (in this case associated with a VI 90-s schedule) may be a powerful conditioned reinforcer in one temporal context, when it is correlated with a reduction in time to reinforcement, and not be a conditioned reinforcer at all in another temporal context, when it is correlated with an increase in time to reinforcement.

Incidentally, the fact that increasing the choice-phase duration decreases the preference expressed for the more valued outcome is consistent with a rich literature on self-control (e.g., Navarick & Fantino, 1976; Rachlin & Green, 1972): The shorter the choice-phase duration the more impulsive the chooser. Thus, if we wanted to reduce fuel consump-

tion by raising fuel taxes, we should make the proposal far in advance of the effective date and also make it somewhat uncertain (say, by making imposition of the tax contingent on the lack of a 10% decline in fuel consumption). Most people find low-valued outcomes more palatable if sufficiently delayed or uncertain.

OBSERVING

DRT has been extended to areas such as self-control, memory, classical conditioning, foraging, and observing. A brief review of the observing area will encompass this paper's central points and also set the occasion for reporting some early data from an ongoing experiment that will bring us back to the issue of the effect of rate of conditioned reinforcement on choice. The general observing procedure, illustrated in Figure 8, was developed by Wyckoff (1952, 1969). A subject's observing response (for Wyckoff, the depression of a pedal by a pigeon) changes a mixed schedule into a corresponding multiple schedule. That is, when the pedal is not depressed a white light is associated with the stimulus key, whether the food schedule is in effect (an FI schedule) or extinction is in effect. Depression of the pedal, however, produces a light that is associated with the schedule in effect (say, red for FI, green for extinction). It is critical to emphasize that pedal pressing has no effect on the rate or distribution of food reinforcement. Observing has a discriminative (or in cognitive terms, informative) function only. Wyckoff's pioneer study with pigeons and scores of subsequent ones have confirmed the robustness of observing: Pigeons, people, monkeys, rats, and fish all observe, despite the fact that observing produces no change in the scheduled rate of primary reinforcement.

This leads to the question: Why does observing occur? A wealth of studies, many from James Dinsmoor's laboratory at Indiana University (including Dinsmoor, 1983; Mulvaney, Dinsmoor, Jwaideh, & Hughes, 1974), have supported the conditioned reinforcement hypothesis of observing, which stipulates that observing is maintained by production of a stimulus correlated with positive reinforcement (and not uncertainty reduction or information per se; for a review, see Fantino,

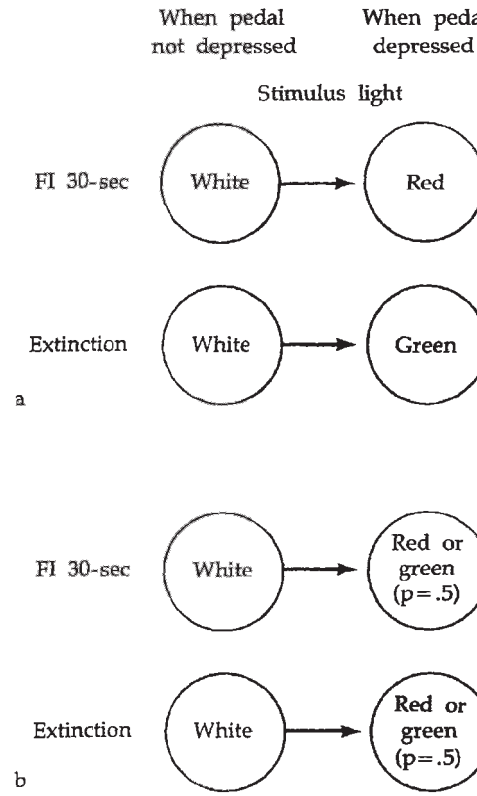

Figure 8. A typical observing response procedure, as originally developed by Wyckoff (1952). In the correlated condition (a, top), the subject's observing response changes a mixed schedule into an analogous multiple schedule. The red and green lights are correlated with an FI 30-s schedule and extinction, respectively. In the uncorrelated condition (b, bottom), the lights produced are uncorrelated with the schedules in effect. They have no discriminative or informative value. If a higher rate of observing is maintained in the correlated condition (and it is), observing is said to be maintained by the production of the discriminative stimuli correlated with the two schedules and not by stimulus change.

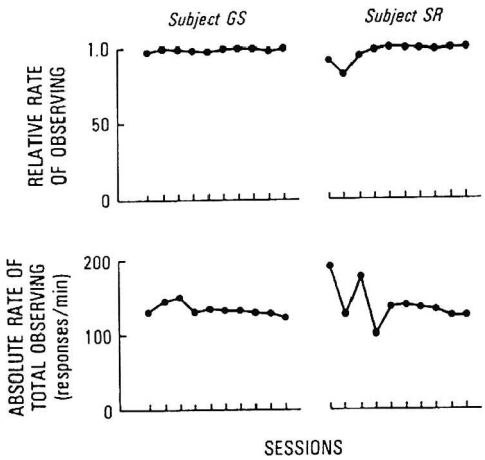

Figure 9. Choice proportions (top) and total absolute rate of observing (bottom) for 2 children in each of 10 sessions. Choice proportions were calculated with respect to the stimulus uncorrelated with reinforcement ("no news"). The children chose between producing this stimulus versus a stimulus correlated with extinction ("bad news"). (From Fantino, Case, & Altus, 1983)

1977; for some of the research with people, see Case, Fantino, & Wixted, 1985; Case, Ploog, & Fantino, 1990; Fantino & Case, 1983). This finding makes sense intuitively: Stimuli paired with a higher likelihood of reward (a reduction in time to reward, in DRT terms, or an increase in value in Mazur's, 2001, terms) are likely to be conditioned reinforcers, whereas stimuli paired with a lower likelihood of reward (or an increase in time to reward or a decrease in value) are unlikely to function as conditioned reinforcers. Colloquially, only "good news" should maintain observing. In fact numerous studies from our laboratory at UCSD have shown that, for humans, compared to "bad news," "no news is good news." The results from one of many studies that support this conclusion are shown in Figure 9 (from Fantino, Case, & Altus, 1983).

This figure plots preference for no news (stimuli uncorrelated with the schedules in effect, and therefore without informative value) over bad news (the stimulus correlated with extinction, therefore a stimulus with informative value but with negative conditioned reinforcing value) at the top, and absolute rates of observing (bottom) for 2 children (9 and 10 year olds). Although these children observed at remarkably high rates (upwards of 100 responses per minute), there was no suggestion of preference for bad news over no news, nor did the strong opposite preference appear to wane over the ten sessions studied.

The work discussed thus far demonstrates that a stimulus correlated with extinction, however informative, will not function as a conditioned reinforcer and will not maintain observing. A more interesting question in terms of pinning down the nature of conditioned reinforcement (i.e., what is the necessary and sufficient condition for conditioned reinforcement) is this: Will the less positive of two stimuli function as a reinforcer? For example, consider the schedule of reinforcement employed by Auge (1974) for his dissertation in Killeen's laboratory at Arizona State University. Auge studied alternating schedules of positive reinforcement. Pigeons could observe which of the two schedules was in effect (see Figure 10, top). Both stimuli are informative, and both are paired with primary reinforcement. Therefore, according to either the traditional pairing view of conditioned reinforcement or the information view, the stimulus associated with the less positive of the alternating schedules should function as a conditioned reinforcer and maintain observing. According to DRT, however, only the stimulus associated with the more positive schedule represents a reduction in time to reinforcement. Thus, only that stimulus should function as a conditioned reinforcer and maintain observing. Thus, looking at Figure 10, we see that for these schedules, the stimulus correlated with the FI 1-min schedule should maintain observing according to all

Auge (1974)

If **no** observing:
MIXED FI 1 FI 5
If **observing**:
MULTIPLE FI 1 FI 5
Time to food correlatedÉ
É with **MIXED FI 1 FI 5**:
3 minutes
É with **FI 1 in MULTIPLE**:
1 minute
É with **FI 5 in MULTIPLE**:
5 minutes

Figure 10. A description of the Auge (1974) experiment and why DRT requires that only the richer of the two component schedules should function as a conditioned reinforcer and maintain observing (the stimulus associated with the FI 5-min schedule is correlated with an increase and not a decrease in time to food).

three theoretical views, but only the pairing and information views predict that the stimulus correlated with the FI 5-min schedule should maintain observing. According to DRT the FI 5-min schedule represents an increase, not a decrease, in time to reinforcement and, therefore, should not function as a conditioned reinforcer. In fact, only the stimulus correlated with the FI 1-min schedule maintained observing.

Thus, at this point we can summarize by concluding that conditioned reinforcers are those stimuli correlated with a reduction in time to reinforcement (or with an increase in time to an aversive event). Extensive research on experimental analogues to foraging behavior (e.g., Fantino & Abarca, 1985; Fantino & Preston, 1988) as well as other areas support this conclusion and the more general view that in order to appreciate the value of an alternative we must consider the context in which that alternative is embedded (Fantino, 2001). Support for this very general conclusion comes too from extensive research on conditioned suppression, including that of Bob Rescorla, and on autoshaping, including the research of Elkan Gamzu and Barry Schwartz and of Bruce Brown and Nancy Hemmes. It is tempting to end our story here (with the word CONTEXT!). However, we have some unfinished business, including some new data.

THE PRIUS EFFECT

We recently purchased a Toyota Prius. The Prius has a display that tells you as much as you might ever want to know about your (and its) fuel consumption: how many miles per gallon you are getting at the moment, how many in each of the past six 5-min periods, and how many on your entire trip (or the life of the car). I used to drive up Highway 5 from our home near San Diego on our way to Mendocino doing 90 miles per hour with my eyes glued to the road ahead. But with the Prius display on the lower right side of my visual field telling me that I had been consuming too much fuel, I now find myself doing 70 miles per hour with my eyes glued to the Prius display. Thus, the Prius display can contribute to two major world problems: energy consumption and overpopulation.

This example is not strictly appropriate in terms of our discussion of observing, because the stimulus changes produced by my observing responses appear to be influencing my driving behavior. A more apt example would involve observing responses that do not influence the miles driven per gallon. This would be my fixating on the Prius display while my wife is driving (because I

dare offer no suggestions to Stephanie on how she might drive). In any event it is clear that the Prius display maintains a high rate of observing, at least in some individuals. Does that mean, all other factors being equal, that the Prius display would make one of those individuals more likely to choose a Prius? This question brings us back to the relation of rates of conditioned reinforcement and choice: Would we choose an outcome in which we emit high rates of observing, that is, in which we are presumably receiving a high rate of conditioned reinforcement? We have a tentative answer based on some recently collected data. Our experiment was inspired by a recent study by Shahan, Podlesnik, and Jimenez-Gomez (2006).

As shown in Figure 11, Shahan et al. (2006) gave pigeons the choice of responding on concurrent schedules that differed only to the extent that each provided a different schedule of observing. The design was elegant and the results unequivocal: Choices matched the rates of observing stimuli produced. These results again raise the theoretical question: Do models of choice in concurrent-chains schedules (such as DRT and the other models cited earlier) require a term for rate of conditioned reinforcement? We had argued not, based on earlier research, including the experiments discussed in this paper (see Fantino & Romanowich, 2007, for a review). But the Shahan results made us think again. Thus, Paul Romanowich, Patty Quan, Joshua Zhang, and I decided to ascertain whether pigeons would prefer an outcome that arranged higher rates of observing (the equivalent of the Prius display). Our procedure is outlined in Figure 12, and our initial data are summarized in Figure 13. Whether the observing schedules are FI or VI, there is no effect on preference. Once again, choice is not influenced by rate of conditioned reinforcement.

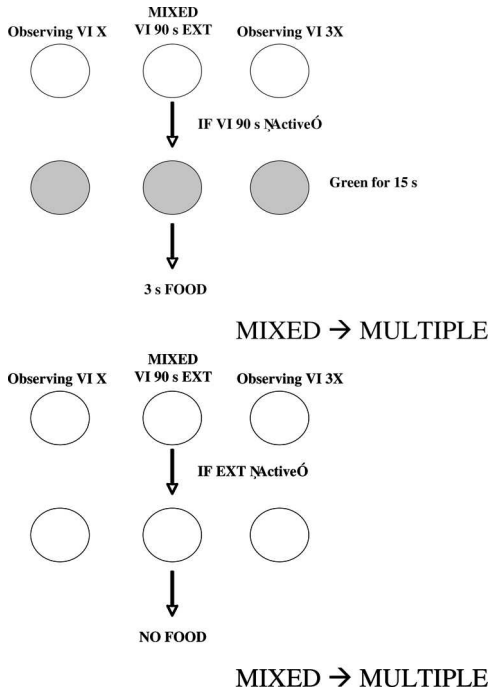

Figure 11. A schematic version of the procedure used by Shahan, Podlesnik, and Jimenez-Gomez (2006). When the VI 90-s schedule was in effect on the food schedule (top), responses on the two observing keys occasionally produced the stimulus correlated with the VI 90-s schedule. But the rate at which observing responses were effective varied across the two observing keys. When extinction was in effect on the food schedule (bottom), observing responses were ineffective.

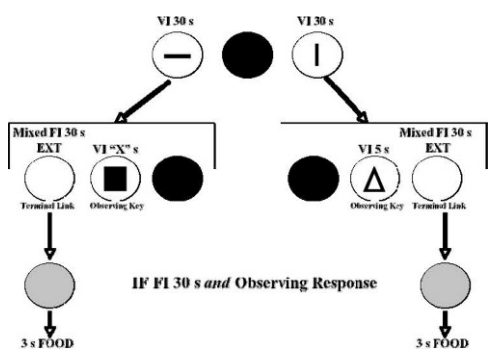

Figure 12. In our study, the rate at which observing responses were effective also varied. However, in this case the observing took place in the terminal links (outcome phase) of concurrent-chains schedules. Would pigeons prefer the outcome with the higher rate of effective observing?

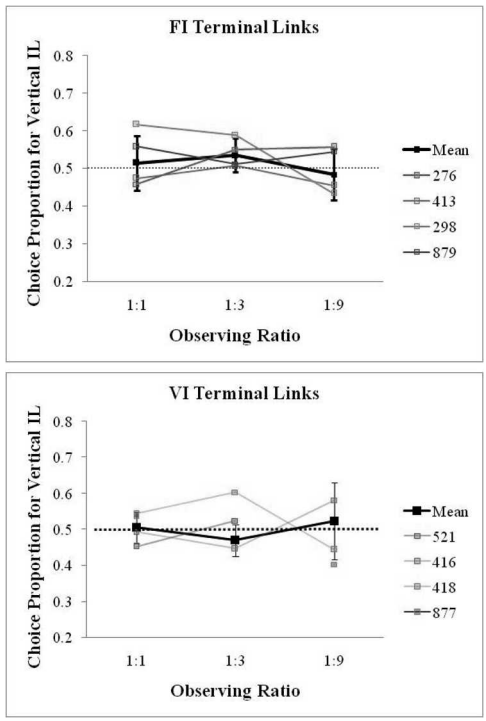

Figure 13. Our initial results suggest that higher rates of observing in the terminal links of a concurrent-chains schedule do not influence preference for those terminal links. This appears to be the case whether the terminal-link (food) schedules are FI (top) or VI (bottom). Data are shown for each pigeon and for the means of the 4 pigeons in each condition.

CONCLUSION

These results may appear paradoxical. On reflection, however, they are not paradoxical or even surprising. The additional conditioned reinforcers in the outcome phase—whether in Schuster's (1969) study, in Squires (1972), in our earlier work, and in our ongoing study—are not correlated with a reduction in time to primary reinforcement (nor with an increase in value, in Mazur's, 2001, terms). Looking at Figure 5 once more, the onsets of the stimuli correlated with the terminal links (outcomes) are correlated with reductions in time to reinforcement (or increase in value). These are the conditioned reinforcers. The superimposed brief stimuli have no such discriminative function. To summarize, only stimuli correlated with a reduction in time to primary reinforcement (or increase in value) are bona fide conditioned reinforcers. And these stimuli *do* profoundly affect preference, as we have seen (and as anyone who has used token reinforcers knows). With this ostensible paradox resolved, we see that the rules that govern choice and conditioned reinforcement are straightforward, though context dependent. These rules have relevance for our everyday behaviors—much of them maintained by conditioned reinforcement—and the decisions we make that shape our lives and world.

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