*APPLIED IMPLICATIONS OF THEORY AND RESEARCH
ON THE NATURE OF REINFORCEMENT*

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When asked to comment on some recently published *JEAB* articles from an applied perspective, we chose the July 1993 issue containing a series of papers on the nature of reinforcement, some of which were presented at the 13th Quantitative Analyses Symposium held at Harvard University in June 1990. At first glance, it seemed that the topic was so central to applied research on operant behavior that we would have difficulty limiting our commentary. Many of the articles, however, focused on either general issues, such as restatement of operant theory from a selectionist standpoint (e.g., Donahoe, Burgos, & Palmer, 1993; Ringen, 1993), or highly restricted laboratory investigations, such as cellular analogues (Stein, Xue, & Belluzzi, 1993), sexual conditioning (Crawford, Holloway, & Domjan, 1993), and autoshaping (Reboreda & Kacelnik, 1993). Although these topics certainly should be of interest to all behavior analysts, they have little immediate relevance to the conduct of applied research. Thus, we selected for commentary one experimental and three review articles whose applied implications are either noted specifically by the authors or should be apparent to readers nevertheless.

Reversibility of Single-Incentive Selective Associations

In 1973, Forsee and Lolordo described results ostensibly showing that for pigeons, visual stimulus control with respect to a food-reinforcement contingency developed more easily than auditory con-

trol, but that the reverse was true for a shock-avoidance contingency. Schindler and Weiss (1982) showed a similar effect with rats, considerably increasing the generality of the phenomenon, considering the striking differences between these two species. This is referred to as a selective association¹ between the sense modality of a stimulus and the nature of the reinforcement related to that stimulus, and is a part of the biological-constraint literature. The usual interpretation is that because of its evolutionary history, a specific type of organism is innately better prepared to acquire visual stimulus-appetitive reinforcement relations and auditory-stimulus avoidance relations.

JABA researchers have not made much use of this result, possibly because food and shock are not common bases for the development of stimulus control with human subjects and because innate propensities are not manipulable. It may also be relevant that the biological-constraint literature has often been presented (but not correctly) as in some way incompatible with the general approach underlying applied behavior analysis. However, the recent work of Panlilio and Weiss (1993) and Weiss, Panlilio, and Schindler (1993a, 1993b) should

¹The language of associations is usually cognitive, and the usage here should not be taken as an endorsement of this verbal practice. The term is not an unreasonable label for a particular environmental history ("the light was associated with food reinforcement," meaning that for the relevant organism, food was available when the light was on and not when it was off); but when the environmental history is said to result in an association between light and food *in or for* the organism, an internal cognitive construct is being identified that can readily become an explanatory fiction.

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make this topic more interesting to the applied researcher. But first, some details.

The Foree and Lolordo (1973) study involved a discrete-trial procedure for developing stimulus control over a treadle-press response with a compound stimulus consisting of a tone and a light (referred to as TL). For some subjects, a response in the presence of the compound stimulus produced food, and for others it avoided electric shock. When the treadle press was under good control by the compound stimulus, the tone and light components were presented separately. For the subjects on food reinforcement, the light exerted much more control than did the tone, but for the subjects whose treadle pressing avoided shock, the tone showed better control than did the light. This differential control occurred even though the two stimulus elements had clearly had exactly the same history with the relevant contingency as parts of the compound stimulus. Schindler and Weiss (1982), with rats as subjects, obtained essentially the same results using a free-operant rather than a discrete-trial procedure.

More recently, Weiss et al. (1993a) identified a confounding effect in the previous research between the type of reinforcement (food or shock avoidance²) and what they referred to as the conditioned hedonic value (p. 311) of the stimulus compound; that is, the extent to which the TL compound (tone and light on) would be expected to function as a conditioned reinforcer or a conditioned punisher with respect to the $\overline{\text{TL}}$ condition (tone and light off). In the previous research, TL was the condition in which responding produced food, and $\overline{\text{TL}}$ was the extinction condition. Here, TL would be expected to function as a conditioned reinforcer relative to $\overline{\text{TL}}$. On the other hand, in the avoidance situation, a shock was given in TL unless a response was made, but $\overline{\text{TL}}$ was a safe condition involving no shocks. Relative to $\overline{\text{TL}}$, the TL condition would be expected to function as conditioned punishment. It was not clear, then, in the previous research, whether it was the type of unconditioned consequence, food versus

shock, or the differential hedonic value (conditioned reinforcer vs. conditioned punisher) of the TL compound that was responsible for the differential control of the two types of stimuli, light versus tone.

Weiss et al. (1993a) wanted to see if differential control by the visual and auditory components of a compound stimulus would be seen using only food reinforcement but with TL having differential hedonic value. They trained one group of rats with the TL compound as a condition during which lever pressing on a variable-interval (VI) schedule produced food, contrasted with $\overline{\text{TL}}$ as an extinction condition. This was a multiple VI EXT schedule, which they identified as TL+, meaning that the TL condition had positive hedonic value (would be effective as a conditioned reinforcer relative to $\overline{\text{TL}}$). The other group of rats responded on a VI schedule in TL, which produced only the $\overline{\text{TL}}$ condition, in the presence of which food was delivered contingent upon 30 s passing without a response. This was a chain VI differential reinforcement of other behavior (DRO) schedule, referred to as TL-, because it would be expected that TL would be a conditioned punisher relative to $\overline{\text{TL}}$. (Even though no unconditioned aversive stimulus is involved, numerous studies have shown that a change from a condition in which reinforcement is available to one in which it is not will function as punishment for the response preceding such a change.) The experiment was highly successful. After training in the TL+ condition, the light exerted much more control over lever pressing than did the tone, but the reverse was true in the TL- condition. In other words, they replicated the Foree and Lolordo (1973) and the Schindler and Weiss (1982) results using only food reinforcement, which they referred to as a single *incentive* condition, as contrasted with the food versus shock incentives of the earlier studies.

In the next study, Weiss et al. (1993b) performed a similar set of manipulations using only shock. One group of rats was on a free-operant shock-avoidance schedule in TL but with no shock in $\overline{\text{TL}}$. For these subjects, referred to as the TL- shock group, TL would be a conditioned punisher relative to $\overline{\text{TL}}$. The other group had the same free-operant avoidance schedule in TL, but in $\overline{\text{TL}}$ re-

²To refer to shock avoidance as a form of reinforcement seems too molar, but this is how the authors described the situation.

ceived noncontingent shocks and each lever press was punished by shock. In other words, for this group TL was a condition in which the shocks could generally be avoided by responding, but in $\overline{\text{TL}}$ shocks were received irrespective of responding, and were also contingent on responding. For this TL+ shock group, TL should become a conditioned reinforcer relative to $\overline{\text{TL}}$. As a systematic replication of the earlier findings, two more groups were subjected to conditions similar to those in the previous experiment, a TL+ food and a TL- food condition. The results for all four groups were as before, with the light showing better control when TL was positive relative to $\overline{\text{TL}}$, but the tone showing better control when TL was negative relative to $\overline{\text{TL}}$, irrespective of whether the positivity was based on a more favorable relation to food or to shock.

The studies described above all involved between-groups comparisons. In the final experiment of this series, the one by Panlilio and Weiss (1993) in the issue of *JEAB* being reviewed, the earlier results were all replicated using a within-subject design. One group of rats was trained on the food-reinforcement schedules, and another group was trained on the shock avoidance schedules. Some of the subjects in the first group were exposed to the TL+ food condition first and then switched to TL- food; the others experienced the conditions in the reverse order. Similarly, some of the subjects in the second group were first trained on the TL+ shock condition and then switched to TL- shock; the others had the reverse order. The results were as before, with the light showing greater control after the TL+ training, and the tone showing greater control after the TL- training, irrespective of the nature of the unconditioned consequence, and irrespective of the order of training. These within-subject results not only confirm the previous findings but also show that the tone-light differences could be reversed by reversing the training conditions.

These results are not, of course, incompatible with the possibility that there is some innate predisposition favoring visual control with food and auditory control with avoidance of aversive stimulation. However, they clearly show another pos-

sible basis for such selective associations, one that is much more relevant to the development of stimulus control in applied research and in behavioral applications. It is not unusual for the applied researcher to provide stimulus conditions and then to use some form of reinforcement to bring behavior under their control. The choice of sense mode may be dictated by the specifics of the application or the availability of stimulus devices, or may be made arbitrarily. There is probably little thought given to what the previous researchers refer to as the hedonic conditioned value of the relevant stimulus condition, whether it would function as a conditioned reinforcer or a conditioned punisher relative to the absence of that stimulus condition. We turn lights on to evoke behavior or to stop it, and the same is true for auditory stimuli. It now appears that we cannot afford to ignore hedonic value when we choose the sense mode (visual or auditory) for some form of stimulus control.

Of course, there is no question that effective stimulus control can be developed with almost any sense mode, irrespective of the hedonic value of the stimulus condition. It is also often the case that instead of a stimulus presence being contrasted with its absence, one stimulus condition is contrasted with a different condition involving the same sense mode; thus, we stop for red lights and go for green lights, and there is little data on stimulus selectivity within a sense mode, although such a possibility is not unreasonable. In any case, it would seem quite prudent, especially for cases in which stimulus control is developed and maintained only with great difficulty, to consider and possibly manipulate the relationship between sense mode and what Panlilio, Schindler, and Weiss are calling the hedonic value of the stimulus condition.

Response Deprivation, Reinforcement, and Economics

Applied researchers have long been aware of the fact that free-operant rates of responding can be used as the basis for predicting reinforcement effects. That is, the opportunity to engage in a response occurring at a relatively high baseline rate, such as watching TV, can serve as reinforcement

for a response occurring at a relatively low baseline rate, such as doing homework. In the first major extension of Premack's principle of reinforcement (Premack, 1959, 1965), also known as the "probability-differential hypothesis," Timberlake and Allison (1974) proposed the "response-deprivation hypothesis" to provide a more thorough account of reinforcement effects derived from relative response rates. Their research showed that, given a baseline condition in which response rates are determined when two responses are allowed to occur freely, a reinforcement effect would occur under a contingency schedule that restricted access to the contingent (reinforcing) response relative to its baseline rate if the subject performed the instrumental (target) response at or below its baseline rate.

Timberlake (1993) and Allison (1993) provided separate discussions of the current status of response deprivation in the July 1993 issue of *JEAB*. The implications of Allison's paper are emphasized here because it focused specifically on response-deprivation research, whereas Timberlake's integration of several approaches to reinforcement theory made only passing reference to response deprivation.

Allison (1993) reviewed a number of studies establishing the generality of the response-deprivation hypothesis and related this work to other research on behavioral economics and performance models based on behavioral "bliss" points that maximize reinforcement. Although there was little emphasis on human affairs, the applied relevance of the response-deprivation hypothesis is evident in its extension of Premack's work in two important respects. First, it predicts conditions under which access to a "high-rate" behavior would not reinforce the occurrence of a "low-rate" behavior (when the reinforcement schedule does not restrict access to the high-rate behavior relative to its baseline if the low-rate behavior decreases relative to its baseline). Suppose, for example, that a subject's baseline ratio of doing homework to watching TV is 1:2. A contingency in which 30 min of homework produces access to 30 min of TV (a homework:TV ratio of 1:1) might be expected to increase homework because it restricts access to TV relative to its baseline rate unless homework increases above its

baseline rate. However, a schedule in which 30 min of homework produces access to 90 min of TV (a homework:TV ratio of 1:3) does not restrict TV if homework does not occur above its baseline rate and, therefore, would not be expected to produce an increase in homework. Although the latter schedule may be an unlikely one in application, such mistakes can be made if contingencies are arranged solely on the basis of relative response rates during baseline. Second, the response-deprivation hypothesis predicts conditions under which access to a "low-rate" behavior could reinforce the occurrence of an already "high-rate" behavior (when the schedule restricts access to the low-rate behavior relative to its baseline rate). Continuing with the homework-TV example, it should be possible to increase TV watching under a schedule in which 30 min of TV produces access to less than 5 min of homework (TV:homework ratio of 6:1). Admittedly, reinforcement of TV watching that already occurs at a high rate may seldom be the target of intervention, but there are a number of instances in which one may wish to produce highly accelerated performances (e.g., as in superlative academic or athletic performance that is good to begin with). In such cases, one need not find another activity that occurs at a higher rate to serve as reinforcement if one could arrange a suitable deprivation schedule with an activity that occurs at a relatively low rate.

In spite of the interesting and potentially useful findings generated by research on response deprivation for over 15 years, there have been very few extensions to the applied area. A notable exception is the work by Konarski. Focusing on a variety of academic performances as target responses, Konarski and colleagues conducted a series of studies on reinforcement schedules based on the response-deprivation model. In an initial experiment, Konarski, Johnson, Crowell, and Whitman (1980) demonstrated that contingent access to a high-probability response (coloring) produced increases in a low-probability response (completing math problems) only when the reinforcement schedule resulted in the restriction of coloring below its baseline rate. That is, when completion of more math problems

than in baseline resulted in access to less coloring than in baseline, time spent on math increased. However, when completion of more math problems than in baseline resulted in access to more coloring than in baseline, time spent on math did not increase. These findings were replicated in a subsequent study on reading and math performance (Konarski, Crowell, Johnson, & Whitman, 1982). Interestingly, access to math (contingent response) was used to reinforce reading performance (instrumental response) for 3 of the subjects, whereas access to reading was used to reinforce math performance with the 4th subject. Finally, Konarski, Crowell, and Duggan (1985) showed within-subject "reversibility of reinforcement" between two responses. In one condition, a response-deprivation schedule with respect to writing (contingent response) produced increases in math performance (instrumental response); in another condition, response deprivation with respect to math (contingent response) produced increases in writing (instrumental response). Taken together, these results exemplify each of the predictions of the response-deprivation hypothesis: reinforcement of a low-rate instrumental response when access to a high-rate contingent response is restricted, nonreinforcement of a low-rate response when access to a high-rate response is not restricted, and reinforcement of a high-rate response when access to a low-rate response is restricted.

In a study just published, Realon and Konarski (1993) provided an interesting extension of response-deprivation methodology to behavioral reduction. After collecting baseline data on self-injurious behavior (instrumental response) and contact with leisure materials (contingent response) exhibited by 2 subjects, the authors arranged schedules in which increases in self-injury above baseline levels produced required contact with leisure materials for durations that exceeded those observed during baseline. Thus, not only did the schedule fail to restrict access to the contingent response (there was no deprivation from contact with leisure materials) but it also specified excessive access to the contingent response. Not surprisingly, the authors found a suppressive effect on self-injury. Although this

arrangement, described as "response satiation," did not completely eliminate self-injury (responding was reduced to 68% and 82% of baseline levels for the 2 subjects, respectively), it provided a convenient means for identifying "punishing" events from among existing activities and further illustrated a practical application derived from response-deprivation theory.

Additional studies translating response-deprivation procedures into real-world application, such as those reported by Konarski and colleagues, would greatly extend the findings of basic research and expand the applied researcher's options for both reinforcement and punishment beyond those based on the Premack principle. As usual, however, a cautionary note is in order. The major limitation of the response-deprivation hypothesis lies in its emphasis on deprivation of responding per se as a key determinant of reinforcement effects. For example, Allison noted that "It no longer seems correct to characterize reinforcement as the result of a special kind of a response consequence called a reinforcer. Instead, reinforcement appears to result from a special kind of schedule called a response-deprivation schedule" (p. 139). This conclusion is problematic for two reasons. First, it is based on the assumption that access to the reinforcing stimulus is available only by emitting a particular response. When access to the reinforcer can be gained through other means (as in response-independent or noncontingent reinforcement), *response deprivation* does not result in *reinforcement deprivation* and will not predict reinforcement effects (see also Michael, 1993, p. 233). Second, in many (perhaps even most) applied situations, baseline rates of responding are themselves determined by contingencies for which the response-deprivation model provides no account. For example, occurrences of both socially appropriate and socially inappropriate behaviors are usually followed by reinforcement of some type that maintains responding at either low or high baseline rates. Response-deprivation schedules may not be necessary for behavior change if the maintaining contingencies can be altered directly and efficiently (e.g., as in increasing the magnitude of reinforcement for appropriate be-

havior or terminating reinforcement for inappropriate behavior). Further, the introduction of response deprivation (or satiation schedules) may not be sufficient for behavior change if the maintaining contingencies for either the instrumental or contingent responses shift during the course of treatment.

The Substitutability of Reinforcers

Most models of reinforcement, including probability differential, response deprivation, and matching, are based on quantitative relationships among response and/or reinforcement rates. By contrast, substitutability theory places emphasis on the qualitative aspects of reinforcement. Green and Freed (1993) discuss general concepts related to reinforcer substitutability, review a series of studies illustrating these concepts, suggest ways in which substitutability extends quantitative models of reinforcement such as the matching law, and draw some applied implications.

The authors define *substitutability* as "a characteristic of the relationship between commodities or reinforcers; thus, substitutability describes a continuum of possible interactions among reinforcers" (p. 142). At one end of the continuum, reinforcers are completely substitutable (e.g., Coke® and Pepsi® as beverages, and grape and strawberry jam as condiments, may be perfectly substitutable for many people). At the other end of the continuum are reinforcers that tend to be used jointly (as in a tennis ball and racket or beer and pretzels). These reinforcers are not substitutable but, rather, are complementary. Drawing from economic theory, Green and Freed noted the interesting relationship between "cost" and "consumption" for substitutable and complementary reinforcers. Cost and consumption of substitutable reinforcers tend to be negatively correlated (e.g., as the cost of Coke® increases, its consumption decreases while the consumption of Pepsi® increases, assuming that the cost of Pepsi® remains constant). On the other hand, cost and consumption of complementary reinforcers tend to positively correlated (e.g., as the cost of tennis rackets decreases, consumption of both tennis balls and tennis rackets increases). Finally, independent reinforcers lie at the middle of

the continuum. For example, tennis balls and pretzels seem to be neither substitutable nor complementary, and an increase in the cost of one reinforcer probably has little effect on consumption of the other reinforcer, except under drastic conditions.

Green and Freed (1993) suggested that an analysis of consumption rates under varying conditions of cost manipulation may provide a means of determining where reinforcers lie along the continuum of substitutability. They described a number of supporting experiments, three of which are summarized here to illustrate the concepts of substitutability, complementarity, and independence. In one study, Kagel et al. (1975) examined rats' responding for different reinforcers under concurrent fixed-ratio (FR) schedules of reinforcement in a closed economy (a fixed number of lever presses was available in a given 24-hr period). Under one arrangement in which the same amount of either Tom Collins or root beer mix was delivered on an FR 1 schedule, the rats showed a strong preference for root beer. However, when the "price" of Tom Collins was halved (by doubling the amount delivered per lever press) and the price of root beer was doubled (by delivering half the amount), preference shifted. The rats now consumed much more Tom Collins than root beer and, in doing so, demonstrated substitutability between the two reinforcers. In another study, Hursh (1978) studied food and water consumption in rhesus monkeys. Water was available for responding on one lever, and identical food pellets were available on two different levers. The water and one food source (constant) were always available on the same VI 60-s schedule, while the schedule of access to the other food (alternative) varied. When the alternative food was made "cheaper" (VI 480 s), responding for the constant food decreased, but responding for water increased. These results demonstrated not only substitutability between the food sources (constant and alternative) but also complementarity between responding for the alternative food and responding for water. Finally, Green and Rachlin (1991) examined choice among food, water, and electrical brain stimulation (EBS) under concurrent variable-ratio (VR) schedules when pairs

of reinforcers were available. Their findings indicated that EBS was substitutable for both food and water, but that food and water were not substitutable for each other. These findings are interesting because they suggest that some reinforcers might be substitutable for others that are not themselves substitutable (as in a token economy in which tokens provide access to either games or food).

After reviewing a number of studies such as those described above, Green and Freed (1993) proposed the concept of substitutability as a means for interpreting one aspect of Baum's (1974) generalized matching law, which attempts to account for situations in which matching does not occur. Green and Freed suggested that sensitivity to reinforcement alternatives (leading to undermatching or overmatching) may be affected by the extent to which qualitatively different reinforcers are non-substitutable. Indeed, results of a recent experiment by Neef, Mace, Shea, and Shade (1992) illustrate this point. In studying students' time allocation on two concurrently available tasks associated with unequal rates and equal versus unequal qualities of reinforcement, Neef et al. found that time allocation was roughly proportional to obtained reinforcement (i.e., consistent with the matching law) when reinforcer quality was equal. However, matching was disrupted when the quality of reinforcement differed across response options. Although support for the inclusion of substitutability as a determinant of matching has been mixed, the influence of reinforcer quality (in addition to factors such as reinforcer frequency, amount, and delay) on choice behavior seems clear.

Reinforcer substitutability in applied research often poses little problem with respect to behavioral acquisition and maintenance. Through trial and error if necessary, one can usually find an effective reinforcer for a given response; as suggested previously, the great appeal of token economies lies in their ability to maintain behavior with reinforcers that lie anywhere along the continuum of substitutability. Behavior reduction poses a much different situation, as can be seen in two studies on DRO contingencies published in *JABA*. Stitzer, Bigelow, Leibson, and Hawthorne (1982) examined the ef-

fects of reinforcement contingent upon drug-free urines in methadone-maintenance patients who often "supplemented" by using benzodiazepine tranquilizers. Subjects whose urine samples tested negative for benzodiazepine were given a choice from among three reinforcers: (a) two take-home methadone doses, (b) \$15 cash, and (c) two single-day opportunities to regulate their methadone dosage. Results showed that the contingency was effective in increasing the frequency of drug-free urines. With respect to the present discussion, the subjects' choices were revealing: the methadone take-home option was selected on 37% of the occasions when reinforcement was earned, money was selected on 63% of the occasions, and dosage self-regulation was never chosen. Thus, given the reinforcement parameters selected by Stitzer et al., money was highly substitutable for benzodiazepine, and methadone was also substitutable when delivered in one form (extra take-home doses) but not in another form (increased clinic dosage).

In another study, Mazaleski, Iwata, Vollmer, Zarcone, and Smith (1993) examined the effects of DRO contingencies on self-injurious behavior (SIB) exhibited by individuals with developmental disabilities. In one condition, occurrences of SIB produced attention from the experimenter (which previously had been found to be the maintaining reinforcer for SIB), and nonoccurrences of SIB produced access to other reinforcers (e.g., food, liquid, music, toys, etc.). This DRO contingency (in which the absence of SIB produced reinforcers different than those responsible for behavioral maintenance) had no suppressive effect on SIB; that is, food, music, and toys were not substitutable for attention. Rates of SIB decreased only when the DRO contingency included attention as the reinforcer.

Neither the Stitzer et al. study nor the Mazaleski et al. study was designed to examine reinforcer substitutability per se; thus, the conditions under which substitutability could have been abolished in the Stitzer et al. study or established in the Mazaleski et al. study were never explored. Both experiments, however, exemplify the relevance of reinforcer substitutability to the study and treatment of behavior disorders. When inappropriate

behavior is maintained by access to a particular reinforcer, the success of differential reinforcement approaches to behavior reduction may depend on the extent to which the new reinforcer (available for either nonresponding or engaging in an alternative response) is substitutable for the former one.

Although the discussion by Green and Freed (1993) extends into theoretical areas well beyond those of interest to some applied researchers, their general treatment of the concept of substitutability is both interesting and easily understood. Applied researchers could provide a unique contribution to our field by undertaking systematic analyses of reinforcer substitutability, which may shed light on the conditions under which arbitrary reinforcers compete with (or complement) those that currently maintain a given performance.

Delay Reduction: Current Status

Fantino, Preston, and Dunn (1993) briefly described delay-reduction theory (DRT) and then surveyed the extensive support for the theory from studies conducted in a variety of experimental settings. Many fascinating forms of evidence are presented for the power and generality of DRT as a way to understand the effectiveness of conditioned reinforcers, but the present commentary will be concerned only with the general implications of DRT rather than the specific information in the Fantino et al. article.

Within the experimental analysis of behavior, the concurrent-chains procedure, first described by Autor (1969), has become the most popular method for studying the relative effectiveness of various events as conditioned reinforcers. In a simple illustration with the pigeon as subject, the procedure involves two response keys located a few centimeters apart on the wall of an experimental chamber, and at first both keys are illuminated white. The pigeon typically makes a few pecks on one key, then pecks the other key, and so on back and forth between the two keys. Eventually, as determined by two VI timers, a peck on a key causes it to change color; for example, the left key becomes red or the right key becomes green, and the other key becomes dark and inoperative. Pecking the key that has changed

color now eventually results in food reinforcement (according to some other schedule of reinforcement), and the procedure starts over again with both keys lit white.

The procedure can be seen to consist of two chain schedules, one related to each key. The relation between pecking the left white key and its changing to red is the left initial-link contingency, which is usually a VI schedule. The relation between pecking the left key after it has changed from white to red and subsequent food reinforcement is the left terminal-link contingency. Similarly, there is a right initial-link contingency for changing the color of the right white key to green (usually the same as on the left white key), and a right terminal-link contingency for obtaining food by pecking the key after its color has changed to green.

With this general procedure, it is reasonable to interpret the color change as conditioned reinforcement for initial-link responding and the food as unconditioned reinforcement for terminal-link responding. If the initial-link VI schedules are equal (e.g., both VI 2 min), then the distribution of responding on the two keys during the initial links should reflect the differential reinforcing value of the stimulus change associated with each terminal link. For example, if the (left) red terminal-link contingency is VI 20 s for food and the (right) green terminal-link contingency is VI 10 s for food, one would expect the pigeon to peck the left white key less often than the right white key, because the red key is less effective as conditioned reinforcement than the green key is.

The basic question raised by such a procedure is how to determine the relative reinforcing effectiveness of the stimuli that are associated with the terminal links. At first, one might assume that this would depend solely on the events taking place in those terminal links. For example, a color associated with a VI 10-s food schedule should be twice as effective as conditioned reinforcement for entering that terminal link as the color associated with a VI 20-s food schedule. In terms of other results with concurrent VI schedules, it might even be expected that the pigeon would show twice as much initial-link pecking on the key with the VI 10-s terminal

link as on the key with the VI 20-s terminal link. It was to provide accurate quantitative predictions in exactly this situation that delay-reduction theory was first developed by Fantino in 1969.

The essential feature of DRT is that it does *not* determine the effectiveness of a stimulus as a conditioned reinforcer solely in terms of events that take place in the presence of that stimulus. Instead, it proposes that the conditioned reinforcing effectiveness of a stimulus "may be predicted most accurately by calculating the reduction in the length of time to primary reinforcement measured from the onset of the preceding stimulus" (Fantino et al., 1993, p. 159). In a simple form of the quantitative relationships, "the reinforcement strength of

$$\text{Stimulus A} = f\left(\frac{T - t_A}{T}\right),$$

where t_A is the temporal interval between the onset of Stimulus A and primary reinforcement and T is the total time between reinforcer presentations" (p. 159). As a specific example, consider the relative value of stimuli associated with two terminal links (such as VI 10-s and VI 20-s food schedules).³ First, let us try to evaluate the two stimuli on the basis of the terminal links alone, as mentioned earlier. From this perspective, it might seem reasonable to consider the color (green) associated with the VI 10-s schedule to be twice as valuable as the color (red) associated with the VI 20-s schedule. Using DRT and the formula above, however, it can be seen that the relative value of the two colors will depend upon the schedule in the initial link. First, let the initial link be a long VI, with an average value of 485 s. Assuming a moderate rate of key pecking on both white keys, the bird will enter one or the other of the terminal links after a little more than 485 s. Assuming that the green and red are entered equally often, there will be a further delay with an average value of 15 s (av-

eraging the 10-s and 20-s delays associated with the green and red key colors, respectively), which makes T , the total time between food presentations, about 500 s. With the formula above, the value of the red stimulus should be $(500 - 10)/500$ or 0.98. Dividing the most valuable by the least results in 1.02. That is, the green is about 1.02 times as valuable as the red. When we perform the same analysis with much shorter interval links, say VI 25 s, we arrive at $T = 40$ s ($25 + 15$), which results in a value for green of $(40 - 10)/40$ or 0.75 and a value for red of $(40 - 20)/40$ or 0.50. Neither color is as effective as conditioned reinforcement now as when the initial links were longer, but relative to each other, the green is now 1.50 times as valuable as the red.

Looking at this analysis from a commonsense perspective, with long initial links the white key is a very unfavorable condition with respect to food compared with the green or red key colors. A change from white to green or from white to red would be a big improvement, and whether it was green or red would make little difference. On the other hand, with short initial links, white is not such an unfavorable condition with respect to food because food is not far away when the keys are white. Under this condition, the change from white to either color is only a moderate improvement, but a further wait of 20 s is long compared to a further wait of 10 s; thus, green seems much better than red. The plausibility of this commonsense reasoning, however, is almost irrelevant, given the highly accurate predictions of the quantitative form of DRT with a wide variety of initial- and terminal-link schedules.

The fact that DRT was developed in a context of concern for quantitative predictions of initial-link performance in concurrent-chains schedules, that values are expressed in temporal units, and that pigeons' key pecking is the usual relevant behavior might imply little significance for those in applied research and practice. This would be quite incorrect, however. The DRT research constitutes strong experimental support for a very important general principle about conditioned reinforcement; one that is easy to overlook in applied

³This is a considerable oversimplification of the quantitative form of DRT. The application of the actual formulae, as in Squires and Fantino (1971), provides a more logically consistent and comprehensive interpretation of the various possibilities.

work. Eliminating the specifics, the theory states that a static stimulus condition cannot be assessed in terms of conditioned reinforcement value. Rather, one must consider the event called conditioned reinforcement to consist of a change from one stimulus condition to another, and the reinforcing effectiveness of this change will depend on the pre-change condition as well as on the postchange condition. It is not the green key or the red key that is a form of conditioned reinforcement. It is the transition from white to green or from white to red that is the conditioned reinforcement in the concurrent-chains procedure and in the environment in general.

Of course this relativity of reinforcement may be arrived at from other perspectives, but the simple elegance of DRT and its quantitative accuracy are compelling reasons to stop evaluating static events or situations for their conditioned reinforcing value and instead to systematically consider both aspects of a relevant stimulus change. To ask whether access to a particular situation (play, work, social interaction, etc.) will function as reinforcement is not a good question. One must ask instead whether a change from one condition to a different one will function as reinforcement, and the answer will depend as much on the characteristics of the condition that is left as the one that is entered. The same logic must be applied to the termination of supposedly aversive conditions. Termination, like access, focuses erroneously on only one half of the relevant stimulus change. (Incidentally, the earlier discussion of selective associations relevant to the Panlilio & Weiss, 1993, article would benefit considerably from this analysis of conditioned reinforcement.)

In addition to its forceful emphasis on the relevance of context to conditioned reinforcement value, DRT research has also been extended to a variety of specific topics of applied interest, such as self-control and foraging. In general, considering the extent to which conditioned reinforcing effectiveness may underlie our interpretation of a large portion of the applied field, DRT should become (and for some may already be) a valuable conceptual tool.

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