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Pavlovian Processes in Simultaneous Discriminations

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Pavlovian associative processes appear to be intimately involved in the acquisition of simultaneous discriminations by pigeons. We have found evidence that in a simultaneous discrimination, value transfers from the positive stimulus (S+) to the negative stimulus (S-) and the basis of that transfer appears to be the higher-order association of the S- with the reinforcer, by way of the S+. Furthermore, the association between the S+ and the S- appears to be bidirectional, occurring in the form of a within event association. In addition, it appears that when pigeons have extended experience with the consequences of responding to the S- stimulus, contrast (the opposite of value transfer) develops between the two (e.g., increasing the value of one, decreases the value of the other). Finally, I suggest that versions of simultaneous discriminations may provide a useful model of several Pavlovian conditioning phenomena including, higher-order conditioning, within-event conditioning, postconditioning devaluation effects, inhibitory conditioning, potentiation, and perhaps also overshadowing.

It has long been recognized that Pavlovian processes play a role in instrumental conditioning. When pigeons peck a response key for food, conditioned stimuli (CSs) might include the light on the pecking key, the proprioceptive feedback from the beak making contact with the key, the sound and feel of the microswitch operating, the sound of the feeder, and the sight of the feeder light. It is also well established that associations acquired using Pavlovian procedures can influence instrumental performance (Rescorla & Solomon, 1967). For example, if during operant barpress performance by rats one presents a CS that earlier had been paired with an aversive unconditioned stimulus (US) one typically observes a decrease in the rate of barpressing (often called conditioned suppression; see e.g., Kamin, 1965).

Very little attention has been paid, however, to Pavlovian processes that might affect the relation between the discriminative stimuli in a simultaneous discrimination. In a simultaneous discrimination, typically, two stimuli are presented and responses to one are reinforced (the positive stimulus or S+) whereas responses to the other are not (the negative stimulus or S-). Kenneth Spence, one of the pioneers of discrimination learning theory, proposed that interactions between the S+ and S- in a discrimination depend on how similar the two stimuli are to each other (Spence, 1937; see also Hull, 1943). Spence did not distinguish between simultaneous and successive discriminations because according to his theory, learning occurs individually to the absolute properties of the stimuli and depends on the number of reinforced responses (excitation) or nonreinforced responses (inhibition) to the stimuli. Spence also proposed that some of the value of the S+ would generalize to similar stimulus values. Thus, if the S- was similar to the S+ the S- would acquire some of the excitatory value of the S+, and the S+ would acquire some of the inhibitory value of the S-. Furthermore, according to Spence, if the S+ and S- are

physically quite different from each other there should be little generalization from one to the other.

An alternative but related model of the interaction between S+ and S- in a simultaneous discrimination was proposed by Fersen, Wynne, Delius, and Staddon (1991). Fersen et al. proposed that in any simultaneous discrimination some of the positive value of the S+ will transfer to the S-, independently of the physical similarity between the stimuli, merely because of their proximity at the time of choice. Actually, there is no reason that Spence should not have anticipated this prediction, given that two important dimensional attributes of all stimuli are their temporal value (when they occur) and their location (where they occur). In the case of simultaneous discriminations, the S+ and S- are presented at the same time and in close proximity, so it is reasonable to expect that some generalization will occur between them.

Fersen et al. (1991), apparently wanting to avoid confusion between similarity based on dimensional values such as color, size, brightness, and shape and those based on time and location called this form of interaction, *value transfer*. Fersen et al. proposed value transfer to account for data they had collected using a nonverbal version of the transitive inference task originally developed by Bryant and Trabasso (1971) for use with children but modified by McGonigle and Chalmers (1977). This task consisted of training on four non-independent simultaneous discriminations made up of arbitrary stimuli (A+B-, B+C-, C+D-, D+E-). The purpose of this task is to create stimulus relations that could be represented as, A is better than B, and B is better than C, and C is better than D, and D is better than E. Thus, if on test trials, a choice is provided between B and D (each of which has served as both an S+ and an S-), B should be preferred. Such transitive inference performance has been taken as evidence for the emergence of a logical relation between these two untrained stimuli (see, e.g., Gillan, 1981). But Fersen et al. proposed that differential value transfer from the S+ to the S- could account for these findings. They suggested that although the direct positive value of B and D should be comparable (as a result of training with the B+C- and D+E- discriminations), differential value associated with the positive stimuli presented with B and D could account for the preference for B over D. According to Fersen et al., B was presented with the always reinforced A, whereas D was presented with the sometimes reinforced C (reinforced when it was the S+ in the C+D- discrimination and nonreinforced when it was the S- in the B+C- discrimination). Thus, A should have more positive value to transfer to B than C has to transfer to D.

Value transfer theory provides an interesting account of transitive inference performance but Fersen et al. (1991) provided no evidence to support this theory. In fact, Weaver, Steirn, and Zentall (1997) have shown that transitive inference performance can be found in pigeons in the absence of differential value transfer. Furthermore, there is a substantial literature indicating that in a successive discrimination, a change in the value of one component generally results in an opposite (contrasting) effect in the unchanged component (Reynolds, 1961). Herrnstein (1970; see also Belke, 1992) has reported similar effects when two schedules of reinforcement are presented at the same time (concurrent schedules). Concurrent schedules are a free-operant analog of simultaneous discriminations. Thus, at the time that value transfer was proposed, there was little evidence that such transfer of value actually occurred during the acquisition of simultaneous discriminations.

A direct test of value transfer theory was conducted by Zentall and Sherburne

(1994). In this research, pigeons were presented with two simultaneous discriminations (presented one at a time) involving distinctive hues. The value of the two S+ stimuli was manipulated by varying the probability of reinforcement associated with choice of each. Thus, in one discrimination, $A_{100}B_0$, responses to A were reinforced on all trials and responses to B were never reinforced. In the other discrimination, $C_{50}D_0$, responses to C were reinforced on 50% of the trials and responses to D were never reinforced. According to value transfer theory, following training, if pigeons are given a choice between the two S- stimuli, they should prefer B over D because A should have more value to transfer to B than C has to transfer to D. In fact, Zentall and Sherburne found that the pigeons selected B over D on almost 80% of the test trials.

In the procedure used in this experiment and in all of the other experiments that we conducted and are described in this article, the hues used were red, yellow, green, and blue, and the hues were counterbalanced such that each hue served equally often as the S+ and the S- in each of the two discriminations. In all experiments the discriminative stimuli were presented on two rectangular closely-spaced response keys (0.5 cm apart) and 5 pecks to either response key terminated the trial. In the first few experiments, the first peck to a response key turned off the alternative key, to prevent the pigeon from switching keys, but in later research this contingency was removed because it was found that the pigeons almost never switched keys after the first response. All correct choices resulted in a 10-s intertrial interval and correct choices also resulted in 2-s access to mixed grain. In all experiments there were 96 trials per session, representing an equal number of each trial type. Acquisition criterion was set at two sessions at or above 90% correct for each trial type. In general, the pigeons were given a single 96-trial test session involving the critical test pair with nondifferential reinforcement for responding, as well a continuation of training trials for at least half of the trials in a test session.

An advantage of the design used in most of the present experiments is that the response measure used to assess stimulus value is a preference test. Thus, variables that might have affected the absolute value of the discriminative stimuli (e.g., the duration of the intertrial interval, the value of reinforcement, the response requirement to the S+) should have had a very similar effect on the two test stimuli.

By What Mechanism Does Value Transfer?

The fact that pigeons show a reliable preference for the S- stimulus that appeared on trials with a higher valued S+ stimulus suggests that Pavlovian stimulus-stimulus associations may be involved in the transfer of value. Viewing this instrumental task from a Pavlovian perspective raises some interesting possibilities. Once the pigeon has learned not to peck the S-, on many trials the pigeon will see the S- and then peck the S+ to obtain the reinforcer. Although an instrumental behavior intervenes between the CS (S-) and the reinforcer (US), the pigeon may still form a direct association between the S- and food via trace conditioning (see Table 1, top). Furthermore, the degree to which the S- is a reliable predictor of food should determine the strength of its association thus, B should receive twice as many reinforced conditioning trials as D.

Alternatively, the S- could be associated with reinforcement indirectly, mediated through the S+ via Pavlovian second order conditioning. In this case, the S+ would represent the primary conditioned stimulus (CS_1) which (given a response) is directly followed by reinforcement, and the S- would represent the secondary conditioned

stimulus (CS_2), a stimulus that is paired with or that signals the presence of the CS_1 (see Table 1, bottom). Although the two CS stimuli are actually presented simultaneously, in fact the pigeon is likely to see them successively (because of their physical separation) and on half of the trials it is likely that the S- will be seen first (see Wright & Sands, 1981). Although each S- should be a prefect predictor of its S+, the strength of the primary S+-food association should determine the preference for the secondary conditioned stimulus.

Table 1
Two Models of the Transfer of Value from the S+ to the S- in a Simultaneous Discrimination.

(1) Direct Conditioning:	CS_2 (S-) --------------------------> US CS_1 (S+)-----> US
(2) Second Order Conditioning:	CS_2 (S-) ----------->CS_1 (S+)-----> US

Note. - CS = conditioned stimulus, US = unconditioned stimulus, S+ = positive stimulus in a simultaneous discrimination, S- = negative stimulus in a simultaneous discrimination.

Rescorla (1980) has proposed that one can distinguish between the direct association of a secondary conditioned stimulus (in this case the S-) with the US and its indirect association, as mediated through the primary conditioned stimulus (in this case the S+) by devaluing the hypothesized mediator. If the CS_2 derives its association with the US through the CS_1, then following the postconditioning devaluation of the CS_1, there should be little evidence of a CS_2-US association (or in the present case there should be a reduced preference for B over D). If, however, the CS_2 was directly associated with the US, one should still find evidence of a CS_2-US association and B should be as strongly preferred over D as it was before.

Zentall, Sherburne, Roper, and Kraemer (1996, Experiment 1) tested these hypotheses. They first trained pigeons on two simultaneous discriminations ($A_{100}B_0$ and $C_{50}D_0$). Then, following a test to confirm that B was preferred over D, half of the pigeons received postconditioning devaluation training with A alone. Devaluation training consisted of single-stimulus extinction of responding to A. The remaining pigeons received postconditioning devaluation training with C alone (the control group). Immediately after devaluation training, the pigeons received a second BD preference test. The design of this experiment is presented in Table 2.

Table 2
Design of Zentall et al. (1996, Experiment 1).

Group	Training	Test 1	Devaluation	Test 2
A-	$A_{100} B_0$ and $C_{50}D_0$	B > D	A_0	B = D
C-	$A_{100} B_0$ and $C_{50}D_0$	B > D	C_0	B > D

Note. To Test the hypothesis that A mediates the association of B with reinforcement. If value transfers from A to B then the postconditioning devaluation of A experienced by Group A- should interfere with that association and reduce the preference for B over D, as it does. The hues, red, green, yellow, and blue served equally often as A, B, C, and D. The subscripts represent the percentage reinforcement associated with responding to the stimulus in training.

Zentall et al. (1996) found that pigeons in the A-devaluation group no longer preferred B over D, whereas those in the C-devaluation group showed a slightly enhanced

preference for B over D (relative to their original preference). Thus, higher-order conditioning involving the S- appears to be involved in the stimulus preference found and hence, in the transfer of value from the S+ to the S- in a simultaneous discrimination.

Within-Event Associations

If higher-order conditioning is responsible for the transfer of value from S+ to S-, it suggests that the association is unidirectional. On the other hand, it also is possible that a backward association develops between the primary CS and the secondary CS. Rescorla and Durlach (1981) have proposed that when conditioning involves two CSs, not only are there associations formed between each of the CSs and the US but there are also bidirectional, within-event associations that may develop between the two CSs.

To test for the presence of within-event S+/S- associations, following discrimination training ($A_{100}B_0$ and $C_{50}D_0$), Zentall et al. (1996, Experiment 2) gave value to one or the other of the S- stimuli (B or D). If the new value acquired by B or D transferred to A or C, respectively, it should be detectable in an AC preference test (see Table 3). If the associations are bidirectional, giving value to D should reduce the preference for A over C relative to giving value to B.

Table 3
Design of Zentall et al. (1996, Experiment 2).

Group	Training	Test 1	Valuation	Test 2
B+	$A_{100} B_0$ and $C_{50}D_0$	A vs. C	B_{100}	A > C
D+	$A_{100} B_0$ and $C_{50}D_0$	A vs. C	D_{100}	A > C

Note. If value given to B after discrimination training (Group B+) retroactively transfers value from B to A it should result in a preference for A over C, as it does. The hues, red, green, yellow, and blue served equally often as A, B, C, and D. The subscripts represent the percentage reinforcement associated with responding to the stimulus in training.

When such valuation training was provided, little evidence for a change in preference for A over C was found. It may be, however, that the large difference in direct value between A and C experienced during training ($A_{100}C_{50}$) prevented the manipulation of the value of B or D from having a detectable effect on test trials.

Assuming that the strong preference for A over C, presumably resulting from direct differential reinforcement of responding to the two S+ stimuli, masked the effect of valuation of the former S- on its associated S+, Zentall et al. (1996, Experiment 3) trained pigeons on two simultaneous discriminations in which the values of the two S+ stimuli (and the two S- stimuli) did not differ ($A_{50}B_0$ and $C_{50}D_0$). In Phase 2, differential value was given to the two S- stimuli ($B_{100}D_0$) and then the S+ stimuli (AC) were tested for preference (see Table 4). Consistent with the hypothesis that within-event associations are established during simultaneous discrimination training, on the AC test, the pigeons showed a modest but significant preference for A over C.

To confirm that this new procedure would also work in the forward direction (S- $\rightarrow$ S+; forward in this case is defined by the temporal position of the food US), a second group of pigeons were trained on two simultaneous discriminations in which the values of the two S+ stimuli (and the two S- stimuli) again did not differ ($A_{50}B_0$ and $C_{50}D_0$) but for these pigeons, in Phase 2, the value of the two S+ stimuli was modified ($A_{100}C_0$; see

Table 4). When these pigeons were then given a BD preference test, consistent with the results of earlier experiments, they showed a preference for B over D. Thus, it appears that following discrimination training, any change in the value of either the S+ or the S- will be reflected in a similar change in the value of the other member of the discriminative stimulus pair.

Table 4
Design of Zentall et al. (1996, Experiment 3).

Group	Training	Phase 2	Test
B+D-	$A_{50}B_0$ and $C_{50}D_0$	$B_{100} D_0$	$A > C$
A+C-	$A_{50}B_0$ and $C_{50}D_0$	$A_{100} C_0$	$B > D$

Note. If an increase in the value of A and a decrease in the value of C retroactively transfers to their respective S- stimuli it should result in a preference for B over D, as it does. The hues, red, green, yellow, and blue served equally often as A, B, C, and D. The subscripts represent the percentage reinforcement associated with responding to the stimulus in training.

In the research described, changing the value of one of the stimuli in a discrimination also entailed presenting that stimulus in the absence of the other. However, the presentation of one element from a compound following compound conditioning should also weaken the within-event association developed during discrimination training. Thus, in the experiment in which a preference for B over D was eliminated by extinguishing responding to A, presentation of A alone may have weakened the within-event association between A and B, independently of the postconditioning devaluation of A. The procedure used by Zentall et al. (1996, Experiment 3) in which both S+ or S- stimuli were presented in Phase 2 controls for the weakening of within-event associations because within-event associations should have been equally weakened for both discriminations.

Another approach to controlling for the effects of weakening within-event associations was examined by Dorrance and Zentall (1999). In this experiment, all pigeons again were trained on two simultaneous discriminations ($A_{50}B_0$ and $C_{50}D_0$) as in Zentall et al. (1996, Experiment 3). Thus, no preference should have been established during initial training. However, in Phase 2, only one stimulus was presented (either A or B) and responses to that single stimulus were reinforced for some pigeons (A_{100} or B_{100}) and not reinforced for others (A_0 or B_0). The four groups in this experiment were designated A+, A-, B+, and B- (see Table 5). The two groups that experienced stimulus A in Phase 2 were then given a BD preference test, whereas the two groups that experienced stimulus B in Phase 2 were given an AC preference test.

Table 5
Design of Zentall et al. (1996, Experiment 3).

Group	Training	Phase 2	Test
B+D-	$A_{50}B_0$ and $C_{50}D_0$	$B_{100} D_0$	$A > C$
A+C-	$A_{50}B_0$ and $C_{50}D_0$	$A_{100} C_0$	$B > D$

Note. If an increase in the value of A and a decrease in the value of C retroactively transfers to their respective S- stimuli it should result in a preference for B over D, as it does. The hues, red, green, yellow, and blue served equally often as A, B, C, and D. The subscripts represent the percentage reinforcement associated with responding to the stimulus in training.

The results indicated that within-event conditioning had occurred in Phase 1,

especially when Phase 2 training involved the S+ from original training. For both Groups A+ and A- there was a strong preference for D over B. Thus, extinction of the within-event AB association greatly reduced the transfer of value from A to B, even for group A+, for which A actually experienced an increase in value. The preference for D occurred because the transfer of value from C to D remained unaffected by single-stimulus presentations of A.

On the other hand, there was also an effect of the valence of A in Phase 2. Although both groups showed a significant preference for D over B on test trials, that preference was significantly greater for pigeons in group A- than it was for those in group A+. Thus, although the association between A and B was weakened by the single stimulus presentations of A, in Group A+, some of the added value acquired by A apparently did transfer to B. When, as in this experiment, the two S+ stimuli were trained with similar value, single-stimulus presentations of one of those S+ stimuli (A) were sufficient to reverse the preference for its associated S- (B). In Experiment 1 of Zentall et al. (1996), however, the value of A_{100} in training was substantially greater than the value of C_{50} and single stimulus presentations of A were insufficient to reverse the preference for B over D.

The data from the two groups that experienced stimulus B in Phase 2 and were then given a AC preference test, showed effects that were quite different. For group B+, there was a significant preference for A over C. Thus, unlike the large negative effect on B of presenting A by itself, for group B+ there was no apparent negative effect on A of presenting B by itself. If there was any effect at all, it was overwhelmed by the positive transfer of value from the now 100% reinforced B_{100} to the 50% reinforced A_{50}.

For group B-, the pigeons were essentially indifferent on AC test trials. Thus, once again there was no apparent negative effect on A of presenting B by itself, and in this case, because there was no change in the value of B from Phase 1 to Phase 2, there was no positive transfer of value to A, and A was unaffected.

Overall, the results of Zentall et al. (1996) and Dorrance and Zentall, (1999) suggest that there are bidirectional within-event associations that develop between S+ and S- in a simultaneous discrimination, but presentation of either stimulus by itself is not necessarily sufficient to disrupt that association. Instead, it appears that (1) positive value acquired following discrimination training can transfer to a stimulus that has less value at the time of test and (2) although single-stimulus presentation of the S+ from original discrimination training appears to weaken the association between the S+ and the S-, single stimulus presentation of the S- from original discrimination training does not appear to weaken the association between the S- and the S+. Furthermore, in both cases, a change in the value of one of the stimuli following original discrimination training can affect the value of the other, a result that not only supports value transfer theory but also indicates that value can transfer retroactively.

Value Transfer or Conditioned Inhibition

The results of research described here suggest that if following discrimination training, the value of one of the stimuli is modified in the absence of the other, that modification can affect the value of the unmodified stimulus. Would similar results be obtained if the two kinds of trial were interspersed rather than occurring in separate phases of training? Thus, if $A_{50}B_0$ and $C_{50}D_0$ discrimination training trials are

interspersed with single stimulus A_{100} and C_0 trials, would one still find a preference for B over D on test trials. Although one could argue that single stimulus A_{100} trials should weaken the association between A and B, C_0 trials should have a corresponding and balancing effect on the association between C and D.

What is provocative about this design is that it presents conditions appropriate for the development of *conditioned inhibition* (or possibly an *occasion setter*-an occasion setter is a stimulus that signals the value of a discriminative stimulus but does not take on the value of that stimulus, Holland, 1983). Consider the role played by the S-stimuli in the mixed-trial design just described. Responding to A is sometimes associated with a high rate of reinforcement (100%, i.e., when it is presented alone) and is sometimes associated with a lower rate of reinforcement (50%, i.e., when it appears with B_0). Thus, B_0 could serve as a signal that the value of A is now lower than it would be if B_0 was not there. In Pavlovian terms, either the reduced value of A should be attributed to B_0 (Rescorla & Wagner, 1972) and B should become a CS-, or if B becomes a negative occasion setter, it should not enter into association with A. In either case, the value of B should not improve with the addition of A_{100} trials. Alternatively, if the value of B is determined by the overall (or average) value of A, then because the overall value of A is better than the overall value of C, B should be preferred over D.

A similar, and perhaps even more convincing argument can be made for the effect of C_0 trials on the $C_{50}D_0$ discrimination. In this case, the presence of D should signal that C has value that otherwise it would not have. Again, in Pavlovian terms, either the increased value of C that is signaled by D should be attributed to D, thus making it a CS+, or if D becomes a positive occasion setter, it should not enter into association with C. Again, in either case, the value of D should not decrease with the addition of C_0 trials. Alternatively, if the value of D is determined by the overall value of C, then because the overall value of C is worse than the overall value of A, once again, B should be preferred over D.

In a series of experiments, Dorrance, Kaiser, and Zentall (1998) found support for value transfer theory. In each case, the pigeons were trained on two simultaneous discriminations in which the schedules of reinforcement associated with the two S+ stimuli (and the two S- stimuli) did not differ (e.g., $A_{50}B_0$ or $C_{50}D_0$). What differed was the value of the two S+ stimuli when presented by themselves (e.g., A_{100}, C_0). Thus, the average values of the two S+ stimuli differed (i.e., they were nominally A_{75}, C_{25}) and those values predicted the S- preference (B over D) on test trials (see Table 6). Furthermore, in separate experiments, increasing the value of one S+ without changing the value of the other S+ (i.e., A_{100}, $A_{50}B_0$ or $C_{50}D_0$, C_{50}) or decreasing the value of the other S+ without changing the value of the first S+ (i.e., A_{50}, $A_{50}B_0$ or $C_{50}D_0$, C_0), resulted in the predicted value transfer effects on preference for the S- stimuli (B over D). Thus, although there is evidence that single-stimulus presentations of the S+ tend to weaken the association between the S+ and S- in a simultaneous discrimination, if one controls for this effect by equating for it in the two discriminations, the value that the S+ can transfer to the S- depends on a combination of its value when paired with the S-, together with its value in other contexts.

Could Value Transfer Result From Differential Inhibition Experienced During Training?

Aitken (1999) has argued that what appears to be value transfer in these studies may actually result from differential inhibition that accrues to the two S- stimuli (see also Couvillon & Bitterman, 1992; Wynne, Fersen, & Staddon, 1992). The argument is that 100% reinforcement to A_{100} in the $A_{100}B_0$ discrimination should lead to few choices of B, whereas partial reinforcement of responding to C_{50} in the $C_{50}D_0$ discrimination should lead to more choices of D. If in training, pigeons make more choices of D_0 than B_0, more inhibition should develop to D than to B and on BD test trials, B should be preferred. This position is based on Aitken's observation that there is a positive correlation across experiments between responding to D in training and the preference for B over D on test trials.

Table 6
Design of Dorrance Kaiser, and Zentall (1998) experiment.

Experiment	Training	Test
1	A_{100}, A_{50} B_0, C_0, C_{50} D_0	B > D
2	A_{100}, A_{50} B_0, C_{25}, C_{50} D_0	B > D
3	A_{100}, A_{100} B_0, C_{25}, C_{100} D_0	B > D
4	A_{100}, A_{25} B_0, C_{25}, C_{25} D_0	B > D

Note. Single stimulus presentations of the S+ stimulus with greater value than it had in the discrimination should cause its S- to become a conditioned inhibitor. However, if mean value of the S+ transfers, the value of the S- should increase, as it does. The hues, red, green, yellow, and blue served equally often as A, B, C, and D. The subscripts represent the percentage reinforcement associated with responding to the stimulus in training.

Although the logic seems sound, there is evidence that is inconsistent with this interpretation. First, in spite of the different reinforcement histories associated with the two simultaneous discriminations, in virtually all of the value transfer experiments, the number of choices of the two S- stimuli did not differ significantly. In some cases, pigeons actually chose B more often than D in training (presumably because of idiosyncratic preexperimental stimulus preferences), yet almost all of them also preferred B over D on test trials. Furthermore, in a similar analysis of the relation between reinforced and nonreinforced experiences with the S+ and S- stimuli in three experiments using a transitive inference design, Higa and Staddon (1993) concluded that reinforcement history with the discriminative stimuli did not predict the presence (or absence) of the transitive inference effect. Instead, they suggest that this effect may depend on dynamic properties of training such as the order in which the training pairs are acquired.

Second, if differential inhibition, produced by the difference in the number of choices to D and B in training, was responsible for the choice B over D in test, then there should be a positive, within-experiment correlation between that difference in training and the preference in test (the larger the difference in the number of choices of D vs. B, the greater the preference should be for B). Instead that correlation was generally negative (although not significantly so).

Perhaps the most convincing evidence against the differential inhibition account

of value transfer comes from Zentall et al. (1996, Experiment 3) in which the two S+ stimuli were given the same direct value in training (as were the two S- stimuli), and the value transfer manipulation was introduced following discrimination training. In this case, there should have been no possibility of differential inhibition. But, of course, strong evidence for value transfer was found (see also, Dorrance & Zentall, 1999).

Aitken (1999) also suggested that stimulus generalization may have played a role in the value transfer effects found because hues were used as the discriminative stimuli and typically the discriminations presented in training involved hues that were not as far apart spectrally as they might have been (e.g., red+yellow- and green+blue-). However, as noted by Zentall, Dorrance, and Clement (1999), traditionally obtained generalization gradients, following single stimulus training (rather than discrimination training which typically produces steeper gradients), indicate that there is virtually no responding to test stimuli that are as spectrally far apart as the hues used in the present value transfer research. Furthermore, in experiments in which there was complete counterbalancing of the hues, not only was value transfer found but the condition in which the strongest value transfer effect was found (97% choice of B over D) was the condition in which the within-discrimination hues were selected to be spectrally farthest apart (i.e., red vs. green and yellow vs. blue; see Zentall et al., 1999). Certainly, if stimulus generalization played a role in these experiments Zentall et al. should have seen some evidence of it. Nonetheless, future research should more directly test Aiken's hypotheses and either assess the effects of differential inhibition and stimulus generalization or control for them.

Negative Value Transfer Versus Contrast

When pigeons acquire a simultaneous discrimination, unless it is acquired without errors, they learn that responses to the S- are not reinforced. And stimuli that are not followed by reinforcement may acquire inhibitory or negative value. If the value of the S+ affects the value of the S- with which it was presented, does the value of the S- also affect the S+ with which it was presented? In other words, to what extent does the presumed inhibition associated with the S- transfer to the S+?

Traditionally, it has been more difficult to assess inhibitory conditioning than excitatory conditioning because it is difficult to distinguish the absence of conditioned responding due to inhibition from the absence of conditioned responding due to neutrality. Thus, by its nature, inhibition must be assessed either on an excitatory baseline or by way of resistance to reinforcement (Hearst, Besley, & Farthing, 1970).

In the case of simultaneous discriminations, the assessment is made even more difficult because the total experience that animal has with the S- is generally more limited than in a successive discrimination. In a simultaneous discrimination, it is sufficient for the tendency to respond to the S+ to be clearly greater than the tendency to respond to the S- for a high level of discrimination performance to be found. That is, the S- can possess substantial excitation as long as it is sufficiently less than the excitation possessed by the S+ to result in consistent choice of the S+. In a successive discrimination, however, the tendency to respond to the S- must be near zero for a high level of discrimination performance to be found because the S- appears by itself. Furthermore, in the case of a successive discrimination, responses to the S- have only minimal negative consequence (a few wasted responses), whereas in a simultaneous discrimination, the consequence of an

incorrect choice is typically the lost reinforcement. As a result, simultaneous discriminations are generally acquired rapidly and experience with the S- is quite limited.

A preliminary experiment exploring the possibility of negative value transfer was reported by Clement, Weaver, Sherburne and Zentall (1998). The design of this experiment (see Table 7) was the mirror image of the design used by Zentall and Sherburne (1994). The idea was to train pigeons on two simultaneous discriminations in which the direct reinforcement value of the two S+ stimuli was equal and the value of the S- stimuli was varied ($A_{100}B_0$ and $C_{100}D_{50}$).

In this experiment, following training, when the pigeons were given AC test trials, no preference was found. However, given the limited experience that the pigeons had with the two S- stimuli (the discriminations were acquired very quickly, with an average of only 13.3 choices of each S- during acquisition and those choices were typically made early in acquisition) it was not clear that this provided a reasonable test of the transfer of negative value. Compare this limited experience with the more than 200 choices (on average) of each S+ during acquisition. That is, there was very little opportunity for inhibition and considerably more opportunity for excitation.

Table 7
Design of Clement Weaver, Sherburne, and Zentall (1998) Experiments.

	Training	Test
Preliminary Experiment	$A_{100}B_0, C_{100}D_{50}$	$A = C$
Experiment 1	$A_{75}B_0, C_{75}B_0$	$A > C$
Experiment 2	$A_{75}B_0, C_{75}D_{25}, B_0, D_{25}$	$A > C$

Note: If negative value transfers, then B should transfer less value to A, than D should transfer to C. However, if there is contrast between the less positive B and A, then the value of A should increase, as it does. The hues, red, green, yellow, and blue served equally often as A, B, C, and D. The subscripts represent the percentage reinforcement associated with responding to the stimulus in training.

To provide a better estimate of the effect that a well experienced S- might have on the S+ with which it is paired, Clement et al. (1998, Experiment 1) made several changes in the design of the preliminary experiment (see Table 7). First, because it is not clear what the effect of partial reinforcement of responding to the S- might have on its associated S+ (D_{50} might either transfer some positive value to C_{100} or draw some value away from C_{100}), the $C_{100}D_{50}$ discrimination trials used in the preliminary experiment were replaced with single-stimulus C_{100} trials. Second, the probability of reinforcement associated with the two S+ stimuli was reduced from 1.00 to .75. This change was made to avoid the possibility of a performance ceiling on AC test trials. More specifically, pigeons given a choice between two stimuli both associated with reinforcement on 100% of the trials may respond to the first stimulus observed. Third, because errors could be made on $A_{75}B_0$ trials but not on single-stimulus C_{75} trials, a correction procedure was used to ensure that the pigeons would experience the same number of reinforcements for responding to A_{75} as C_{75}. Finally, to ensure adequate exposure to the consequences of responding on B_0 trials, single-stimulus presentations of B_0 were included during training. Thus, training consisted of discrimination trials involving $A_{75}B_0$, and single stimulus trials involving C_{75} on some trials and B_0 on others. If negative value transfers from B to A as the result of $A_{75}B_0$ training, then pigeons should prefer C over A on test trials. Instead, Clement et al. found a strong (71%) preference for A over C. The results

of this experiment suggest that the presence of an S- may actually enhance the S+ with which it is paired.

The rationale for deleting D from the C+D- discrimination was to avoid the problem of predicting the effect on C of giving some value to D. But given the finding that A was preferred over C, it is possible that single-stimulus presentations of C introduced an artifact–namely, that A appeared in the context of a choice in both training and test, whereas C appeared in the context of choice, only in test. Thus, on test trials, the novelty of the choice context for C may have biased the pigeons to choose A.

In Experiment 2, Clement et al. (1998) corrected this problem by replacing single-stimulus presentations of C with a CD discrimination in which D had direct value greater than zero and the pigeons experienced single-stimulus presentations of the two S-stimuli ($A_{75}B_0$, $C_{75}D_{25}$, B_0, D_{25}; see Table 7). Once again, following acquisition, the pigeons were given a choice between A and C and once again they preferred A. Thus, the preference for A in the first experiment did not depend on the absence of choice trials involving C in training.

The results of these experiments suggest that in a simultaneous discrimination, whereas positive value transfers to the negative stimulus, negative value does not transfer to the positive stimulus. (When pigeons were trained, $A_{100}B_0$ and $C_{100}D_{50}$, and tested with B vs. D, no preference was found.) In fact, if adequate experience is provided with the negative stimulus, contrast or positive induction results and the contrast enhances the value of the positive stimulus with which it was paired.

Although single stimulus presentations of the S- stimuli did appear to produce contrast in the simultaneous discriminations, it could be argued that those single-stimulus presentations effectively converted the simultaneous discriminations into successive discriminations (i.e., A_{75}, C_{75}, B_0, D_{25}). But if single stimulus training with the S- stimuli converted the simultaneous discriminations into successive discriminations, it is not clear why *differential* contrast would occur. That is, were it not for the $A_{75}B_0$, and $C_{75}D_{25}$ associations developed during training, it is not clear why B should be contrasted with A rather than with both A and C and why D should be contrasted with C rather than with both A and C. Thus, nonreinforced experience with B (as well as D) should have had the same effect on C as on A.

The presence of single-stimulus trials appears to be necessary to produce the contrast effect found by Clement et al. (1998). Is it possible that the inclusion of single-stimulus trials among discrimination trials will generally convert the relation between S+ and S- from value transfer to contrast - even in a positive value transfer design? Clearly, single-stimulus trials are not sufficient to produce contrast because Dorrance et al. (1998) found value transfer when single stimulus presentations of the S+ stimuli were included in training. However, in each of the experiments reported by Dorrance et al., the value of at least one of the S+ stimuli changed when it was presented as a single stimulus. However, for contrast to occur, it may be sufficient to have single-stimulus presentations of the S+ stimuli and for the value of those S+ stimuli to be the same as they are in the context of the simultaneous discrimination. To test this hypothesis, Clement et al. (1998) included a positive value transfer group in their second experiment and they added single-stimulus presentations of the S+ stimuli in training ($A_{100}B_0$, $C_{50}D_0$, A_{100}, C_{50}). Consistent with value transfer theory, on BD test trials, the pigeons preferred B over D on 70% of the trials. Thus, single stimulus presentations of the S+ stimulus from the simultaneous discrimination are not sufficient to convert value transfer to contrast. However, single-

stimulus presentations of the S- do appear to be sufficient to produce contrast.

Recall that in the positive value transfer design, the value of the S+ is varied and its effect on the S- stimulus is assessed on test trials. Thus, one could argue that the single stimulus presentation of the S- stimuli in Clement et al.'s (1998) second experiment should have reduced or eliminated the effect of the S+ on the S- with which it was paired. That is, whatever value has been attributed to the S- based on its association with its S+ should have been reduced by direct experience with the S- when presented by itself. Clement and Zentall (2000, Experiment 1) tested this hypothesis in a design similar to that used by Zentall and Sherburne (1994). Pigeons were trained on two simultaneous discriminations with choice of one S+ reinforced on 100% of the trials and choice of the other S+ reinforced on 50% of the trials (see Table 8). Single stimulus presentations of the two S- stimuli were also included. To ensure that the pigeons had similar direct experience with both S- stimuli, the stimuli were each given a small value, sufficient to maintain responding on single-stimulus trials. Furthermore, that small value was also nominally given to the S- stimuli when they appeared in the simultaneous discriminations ($A_{100}B_{12.5}$, $C_{50}D_{12..5}$, $B_{12.5}$, $D_{12.5}$). Surprisingly, when the pigeons were given BD test trials, they showed contrast or negative induction in the form of a strong preference for D over B. Furthermore, in a follow-up within-subject experiment, Clement and Zentall (2000, Experiment 2) demonstrated that if there was little experience with the S- during original training, value transferred from S+ to S- but when training was continued and single-stimulus S- trials were included, contrast resulted (see Table 8). Thus, when pigeons that had just shown value transfer were given increased experience choosing the S- stimuli, they reversed their preference and showed negative contrast (or negative induction).

Table 8
Design of Clement and Zentall (2000) Experiment.

	Training	Test
Experiment 1	$A_{100}B_{12.5}$, $C_{50}D_{12.5}$, $B_{12.5}$, $D_{12.5}$	B < D
Experiment 2		
Phase 1	$A_{100}B_{12.5}$, $C_{50}D_{12.5}$, A_{100}, C_{50}	B > D
Phase 2	$A_{100}B_{12.5}$, $C_{50}D_{12.5}$, $B_{12.5}$, $D_{12.5}$	B < D

Note: If sufficient experience with the S- is responsible for contrast as opposed to value transfer then single-stimulus S- training should decrease the value of the S- paired with the greater valued S+, as it does. The hues, red, green, yellow, and blue served equally often as A, B, C, and D. The subscripts represent the percentage reinforcement associated with responding to the stimulus in training.

The above research indicates that in a simultaneous discrimination, value will typically transfer from the S+ to the S-. However, when increased responding to the S- is provided in the form of single stimulus presentations, the effect of the S+ is to reduce the value of the S- even further. In other words, relative to the S+ the S- is worth even less.

An interesting prediction can be derived from the above analysis. The discrete trial simultaneous discrimination described here is similar in many ways to an operant concurrent-schedules procedure in which a pigeon is given a choice between a signaled relatively rich schedule, A, on one response key (e.g., a variable interval, VI, 20 s schedule) and a signaled poorer schedule, B, on the other response key (e.g., a VI 40 s schedule). According to the matching law (Baum, 1974; Herrnstein, 1970), pigeons will

typically respond more to the key with the richer schedule and they should distribute their responses in proportion to the relative rate of reinforcement (i.e., in this case, two to one in favor of the VI 20 s schedule). If the pigeon also acquires a second pair of signaled concurrent schedules; C, VI 40 s and D, VI80 s schedules, and it is then given a choice between the two VI40 s schedules, B and C, what should the effect of the richer VI20 s schedule be on the poorer VI 40 s schedule as compared with the effect of the poorer VI80 s schedule on the richer VI 40 s schedule? If value transfers from the richer to the poorer schedule then B should be preferred over C, however, the results of this experiment indicated that C was chosen over B (Belke, 1992). On the other hand, the results of several experiments presented here suggest that in the discrete-trial procedure, value transfer depends on the limited experience that the pigeon has with the stimulus associated with the poorer schedule (i.e., the S-). When the pigeon is given extensive experience with the S-, contrast results. In the case of concurrent schedules, it can be argued that the pigeons have had extensive experience with the less preferred stimulus, thus one would expect contrast to develop and the VI40 s schedule that was experienced in the context of the richer VI20 s schedule should appear to be a poorer schedule than the VI40 s schedule that was experienced in the context of a poorer VI80 s schedule.

Predictions

The idea that the amount of experience with the S- in a simultaneous discrimination will determine whether value transfers from the S+ to the S- or contrast develops between the two stimuli suggests that a parametric manipulation of experience with the S- in a simultaneous discrimination would yield the following results. Early in training, prior to a high level of discrimination performance, the S+ should have little effect on the S- with which it is paired. With additional training, the S+ should transfer some of its value to the S-. However, if additional experience is provided with the S- (by means of single stimulus training), the added value provided by the S+ should decrease and contrast (or negative induction) should be found.

The idea that value transfer is a form of stimulus generalization resulting from the temporal and spatial contiguity of the S+ and S- stimuli leads to the prediction that increasing the spatial separation between the two stimuli should decrease the amount of value that transfers. In the present research the response keys were close together (only 0.5 cm apart). If the mechanism underlying value transfer is correct, the transfer effects should be reduced by placing the keys further apart. A similar prediction can be made for an increase in temporal separation, although we already know that successive discriminations result in contrast, perhaps produced by the increased experience that the pigeons have with the consequences of responding to the S- stimulus.

Extrapolation to Other Pavlovian Phenomena

Simultaneous Discriminations as a Model of Pavlovian Potentiation

When two stimuli are presented at the same time ($CS_1 + CS_2$), the more easily conditioned stimulus may retard the conditioning of the other, relative to a control group that is trained on the less easily conditioned stimulus by itself. This phenomenon first reported by Pavlov (1927) in known as overshadowing.

Interestingly, the opposite effect has also been found. Under certain conditions, presenting a stimulus in compound with another stimulus can augment the response to the first. This effect, known as potentiation, has been demonstrated, for example, in rats with odor as the CS and poison as the US (Rusinak et al., 1979). The rats in this study developed only a weak aversion to a novel almond scent. However, if the almond scent was paired with a novel saccharin taste, the rats developed a much stronger aversion to the almond scent. But potentiation is not limited to stimuli from strongly related modalities. Potentiation of visual stimuli by taste stimuli also has been found (Best & Meachum, 1986; Lett, 1984).

Flaherty (1985) has suggested that potentiation may depend on the sequential presentation of two conditioned stimuli, with the potentiated stimulus (e.g., the odor cue) preceding the more easily conditioned stimulus (e.g., the taste cue). Thus, potentiation may occur when one cue (e.g., the taste) mediates the association between the second cue (e.g., the odor) and the unconditioned stimulus.

The critical aspects of potentiation appear to be (1) that the potentiated conditioned stimulus is not easily associated with the unconditioned stimulus (odor with illness in the absence of a taste cue), (2) that the potentiated stimulus is easily associated with the other conditioned stimulus (odor with taste), and (3) that the other conditioned stimulus is easily associated with the unconditioned stimulus (taste with illness). Although the context appears to be quite different, the typical simultaneous discrimination may provide a reasonable model of the conditions under which Pavlovian potentiation is found (see Rescorla & Durlach, 1981, for a discussion of the role of within-event learning in potentiation).

In the case of a simultaneous discrimination, the three critical aspects of potentiation are produced not through inherent characteristics of the two conditioned stimuli and the unconditioned stimulus but through the conditions of reinforcement and nonreinforcement, and the temporal-spatial relations between the two conditioned stimuli. First, because responding to the S- is not reinforced, responding to the S- should drop out quickly and the S- is not likely to acquire very much conditioned inhibition. However, on at least half of the trials, the pigeon is likely to have seen the S- before responding to the S+ and obtaining reinforcement. Thus, the direct (trace) association formed between the S- and the US is likely to be quite weak (Zentall et al., 1996). Furthermore, Zentall et al., found that the association between the S- and reinforcement may be mediated by the S+ in the form of higher-order conditioning. If the S- serves as a signal for the presence of the S+, then the S- should be easily associated with the S+. If higher-order conditioning is responsible for the S- $\rightarrow$ US association, it satisfies the second characteristic of conditioned stimuli predicted to result in potentiation - that is, that the weaker CS (e.g., odor) should be easily associated with the stronger CS (e.g., taste). Support for the idea that the S+ may serve to mediate the association between the S- and reinforcement comes from Rescorla (1982). In a series of experiments, Rescorla found that relatively poor conditioning found using a trace conditioning procedure could be facilitated by inserting a stimulus in the interval between the CS+ and the US. In this case, the inserted stimulus served a function similar to that of the S+ in a simultaneous discrimination, tying together the instrumental S- (or the trace Pavlovian CS+) with the reinforcer.

Finally, potentiation appears to depend on the easily formed association between the potentiating stimulus and the unconditioned stimulus. Although there is no special

relation between the S+ and reinforcement, in a typical simultaneous discrimination all responses to the S+ are followed by reinforcement and rapid learning to respond to the S+ by pigeons suggests that the S+-reinforcer association is easily acquired. The fact that an S- associated with an S+ to which responses are continuously reinforced is preferred over an S- associated with an S+ to which responses are partially reinforced suggests that the strength of the S+ - reinforcement association is important to the degree of preference for the S-.

Thus, taken as a whole, the previous discussion suggests that acquisition of simultaneous discriminations appears to satisfy the conditions of Pavlovian potentiation outlined. The three factors proposed here that contribute to Pavlovian potentiation easily can be manipulated in the context of a simultaneous discrimination. For example, one should be able to manipulate the association between the S- and the reinforcer by varying the spatial distance (and thus the temporal distance) between the S+ and the S-. Similarly, the spatial distance between the S+ and S- should affect the strength of the association between them. Finally, the schedule of reinforcement associated with the S+ should affect the strength of association between the S+ and reinforcement. Thus, it should be possible to manipulate the degree of potentiation independently of the natural (preexperimental) relations among the stimuli (e.g., odor and taste) or lack of relations among the stimuli (e.g., visual and auditory stimuli).

Simultaneous Discriminations as a Model of Pavlovian Overshadowing

It also may be possible to model other Pavlovian phenomena using variations of simultaneous discriminations. For example, if one reinforces responses to the choice of either discriminative stimulus would that result in an analog of overshadowing? Overshadowing appears to occur when one of two conditioned stimuli presented in compound is more easily associated with the unconditioned stimulus that is the other and the conditioned stimuli are not easily associated with each other. What if pigeons are presented with Sa+ together with Sb+? Under these conditions, all things being equal, pigeons often develop stimulus preferences. Assuming they do, one can hypothesize that the less preferred S+ (Sb) may be overshadowed by the more preferred S+ (Sa). Evidence that this may represent a kind of overshadowing would come from a yoked control condition in which Sc+ would be presented alone as often as Sb+ was chosen and on test trials the pigeons preferred Sc over Sb. Of course, it would be necessary to counterbalance the stimuli used as Sb and Sc to ensure that preexperimental stimulus preferences were not responsible for the test results.

The general discussion presented here suggests that, the acquisition of simultaneous discriminations can serve as reasonable model of various conditioning effects including higher-order conditioning, within-event conditioning, postconditioning devaluation effects, inhibitory conditioning, potentiation, and perhaps also overshadowing. But the ability to model Pavlovian processes using simultaneous discriminations is not just an academic exercise. By using arbitrary stimuli and manipulating the reinforcement histories associated with each of the discriminative stimuli, one may be able to identify the conditions under which each of these phenomena will occur.

The interaction between Pavlovian and instrumental conditioning processes has long been acknowledged, to the degree that they appear to be very difficult to dissociate.

The present research may add a new facet to that relationship. If simultaneous discrimination learning can be used as means of modeling various Pavlovian processes it may provide a useful tool to understand their underlying mechanisms.

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