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CONTINUITY THEORY REVISITED: REJECTED FOR THE WRONG REASONS?[1]

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A simulation of the original Spence discrimination model is presented. Both the overlearning reversal effect and reversals being faster than nonreversals are shown to be within the scope of the model without modification. Both findings had previously been considered as evidence against any continuous, nonselective theory of discrimination learning.

A generally accepted dictum is that one should not reject a decent scientific theory without sufficient reasons. Judging from current trends, Spence's (1936) original model for discrimination learning is believed to have been rejected by two kinds of results, among others: (*a*) that overlearning on an initial discrimination can sometimes facilitate subsequent reversal learning (the ORE), and (*b*) that reversal shifts are sometimes achieved more rapidly than are nonreversal shifts. It has been argued, and apparently accepted, that such results require a "two-process" mediational or attentional model in contrast to Spence's "one-process" continuity theory. The purpose of the present paper is to show that this argument is misguided, that Spence's original model can "explain" such results, and so these alone constitute insufficient reasons for rejecting the theory.

THE THEORY

Spence's theory about the learning of simultaneous discriminations is clearly expounded in his 1936 paper, with illustrative parameter values and a few hand simulations worked out in detail. In brief, for N binary dimensions (e.g., brightness, position, shape), one defines $2N$ habit strengths, H_i, where each refers to the approach-eliciting potential of a particular stimulus component. Thus, for a simple black-white discrimination with left-right position irrelevant, one would identify four component habit strengths, for approach to black, white, left, and right. For predicting choice on a particular trial, one sums the strengths of the individual components contributing to a left versus a right choice, and assumes that S chooses that stimulus complex with the higher summated strength (if the two are equal, then S chooses randomly). The reward or nonreward outcomes which follow the choice are assumed to alter the strengths of the components of the chosen stimulus complex. If the response is rewarded, then each component in the rewarded stimulus complex has its strength increased by an amount depending on its current strength. In particular, for scaling strengths on a 0–100 scale, the increment was assumed to be a bell-shaped function of the strength, with a maximal increment occurring when $H = 50$ and falling off in a Gaussian manner for H values away from 50. Contrariwise, if the response was nonrewarded, then each component of the nonrewarded stimulus complex has its strength decreased by an amount proportional to its current strength, that is, stronger habits are decremented more by a nonreward.

THE SIMULATION

The parameter values for increments and decrements from Spence's 1936 paper were used in the following simulation. The parameters varied were the initial strengths of the four component habits at the outset of original training (the so-called "start vector"). For each start vector, four groups of "stat rats" or Monte Carlos were run ($n = 100$ per group) corresponding to the experimental procedures of reversal (R), nonreversal (NR), overtraining before reversal (OR), and overtraining before nonreversal (ONR). The simulations were run on a PDP 1 computer using a modified version of Algol. The four values in the start vector (initial habit strengths) were varied in steps of 10, starting with initial values of 10 each. In parameter regions which ap-

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TABLE 1

TRIALS AND ERRORS TO CRITERION FOR A SAMPLE OF START VECTORS

Line	Starting habits in original learning				OL	R	NR	OR	ONR	Measure
	Relevant dimension		Irrelevant dimension							
	+	−	+	−						
1	16	14	80	82	11.8	53.6	43.3	100.4	53.3	Trials
					.6	27.3	11.5	66.5	19.3	Errors
2	80	68	16	14	10.0	17.0	19.8	21.8	20.2	Trials
					0	6.1	3.8	10.0	5.4	Errors
3	90	88	10	12	12.4	14.6	31.8	30.8	22.0	Trials
					.8	3.3	12.2	13.4	6.1	Errors
4	20	20	80	80	10.5	32.7	28.6	62.0	42.2	Trials
					.5	16.6	8.1	42.0	14.5	Errors
5	50	50	50	20	35.8	50.3	18.3	39.3	30.0	Trials
					11.0	20.7	3.7	25.0	10.0	Errors
6	50	80	20	80	51.6	44.8	18.0	36.3	28.1	Trials
					19.1	19.2	4.5	22.0	9.5	Errors

Note.—The trials measure includes the criterion run of 10 correct. OL = original learning, R = reversal, NR = nonreversal, OR = overlearning reversal, ONR = overlearning nonreversal.

peared interesting, the step size was reduced to two. The sequential generation of choice stimuli (e.g., whether white appeared on the left or right) was random with the restriction that in each 20-trial block, white appear equally often on the left and right. After a stat rat met an initial learning criterion of 10 successive correct responses, it was then randomly assigned to Condition R, NR, OR, or ONR. Overtraining was 100 trials past the initial criterion before the problem shift. After the R or NR shift, the stat rat was run to a second criterion of 10 successive correct responses.

RESULTS

The computer output consists of group means for trials and errors to criterion for original learning and for reversal or nonreversal learning. The absolute magnitudes of these numbers depend on the learning rate parameters assumed and are probably of no importance; however, the relative ordering of the four experimental conditions is of importance and would probably be relatively invariant over small changes in Spence's learning rate parameters.

In overview, for a large variety of start vectors (habit strengths before original training) in the four-dimensional parameter space, we have OL scores and four group means, for R, NR, OR, and ONR. A selected sample of these is shown in Table 1 from which some interesting comparisons will be made.

A first important statistic was that for 25% of the start vectors, the model predicted faster reversal learning following overlearning than without overlearning. Lines 5 and 6 of Table 1 provide two examples of a predicted ORE in terms of trials to a reversal criterion (though not in terms of errors). Within the overall sample, there was a fairly strong correlation between the difficulty of original learning and the relative ordering of Groups R and OR on trials to a reversal criterion. In particular, the OR group tended to reach the reversal criterion faster than Group R when the original problem was difficult as indexed by many trials to an original-learning criterion. In Table 1, comparison of OL for Lines 5 and 6 (which show the ORE) with Lines 1, 2, 3, 4 (which do not) illustrates this correlation in the model. This pattern of theoretical outcomes corresponds to the ORE pattern in data claimed by Lovejoy (1966). He proposed that the ORE usually appeared when the relevant dimensions had low initial salience, leading to slow original learning, whereas overlearning retarded reversal when the relevant dimension was initially salient, producing rapid original learning.

The authors examined the experimental literature for a correlation between speed of original learning and occurrence of the ORE. There are several problems in conducting such a search. Many papers do not report trials to original learning, and those that do use a variety of learning criteria. An additional minor irritation is ambiguity in whether a report of "40 trials" to a criterion of, for example, 10 consecutive correct means that the subject made his last error (before his 10 correct) on Trial 30 or on Trial 40.[3] Such problems produce hazards in comparing original learning across different experiments. Nevertheless, the authors found 14 experiments which used reasonably uniform learning criteria and which reported original learning. Nine of these agreed with the general correlation in the simulations, in that slow original learning led to an ORE, while fast original learning led to the opposite of an ORE (Brookshire, Warren, & Ball, 1961; Bruner, Mandler, O'Dowd, & Wallach, 1958; Hill & Spear, 1963; Komaki, 1961; Mackintosh, 1962, 1963a; Pubols, 1956; Reid, 1953; Williams, 1942). Five experiments did not support the correlation (Clayton, 1963; D'Amato & Jagoda, 1961, 1962; D'Amato & Schiff, 1964; Erlebacher, 1963). In addition, eight other experiments offer support to the simulation on ORE, although their designs make the interpretation somewhat more uncertain than for those previously cited (Capaldi, 1963; Hill, Spear, & Clayton, 1962; Ison & Birch, 1961; Mackintosh, 1963b, 1965; North & Clayton, 1959; Theios & Blosser, 1965; Wike, Blocher, & Knowles, 1963). This kind of "box-score" tabulation is, at best, a lame method for validating a theory because (*a*) cross-experimental comparisons are hazardous, (*b*) the theoretical correlation (between original learning and the ORE) is not perfect, and (*c*) changes in the theoretical learning parameters as well as the start vector might change the relative ordering of Groups R and OR. The conservative conclusion is that the variability in ORE outcomes produced by Spence's model is about commensurate with the variability of experimental outcomes on the ORE. A more definite conclusion is that demonstration of an ORE does not in any way invalidate Spence's model.

A second statistic of interest in the simulations is that for 20% of the start vectors, the model produced faster reversal learning than nonreversal learning, contrary to a prevailing belief (e.g., Kendler, Kendler, & Wells, 1960). Examples of this ordering occur in Lines 2 and 3 of Table 1, where Group R reaches criterion faster than Group NR either with fewer errors (Line 3) or with more errors (Line 2). The simulations produced faster reversal than nonreversal learning when the start values in the model were high for the relevant cues and low for the irrelevant cues. However, this particular combination of start values is not well correlated with speed of original learning by the model. For example, Line 1 for the opposite ordering of start values predicts NR to be easier than R, yet original learning is as fast as for the cases in Lines 2 and 3. So speed of original learning is not a covariate permitting even approximate specification of the rank ordering of R and NR groups. But a definite conclusion is that demonstration that reversal learning proceeds faster than nonreversal learning does not invalidate Spence's model.

The ONR condition has been less studied in the experimental literature than the other conditions, but the model's predictions may be discussed. First, it is clear that the start vector affects the relative ordering of the NR and ONR conditions (compare Line 1 with Line 3), as well as the outcome pattern comparing R versus OR to NR versus ONR. The simulations indicate that in most cases where R proceeds faster than NR, overlearning facilitates nonreversal, that is, ONR takes fewer trials to criterion than NR (Line 3 is an example). Another generalization is that in those cases where an ORE occurs (OR $<$ R on trials to criterion), overlearning will often retard nonreversal learning (NR $<$ ONR); Lines 5 and 6 exemplify this ordering of the groups. While tests of these relationships are quite infrequent in the literature, Mackintosh (1962) has reported data consistent with them.

CONCLUDING REMARK

This paper has shown that Spence's original model can predict an ORE and faster reversal than nonreversal shift with suitable choice of the initial habit strengths. However, the authors do not know of any means by which these start values could be estimated numerically from the data of a single experiment. Since the predicted ordering of R versus OR groups and R versus NR groups depends on these unknown parameters, the authors do not see how such experimental comparisons can be at all relevant to validating the theory. By the same token, *such results are not relevant to infirming the* theory, as has sometimes been claimed.

Showing that Spence's model is not inconsistent with the results from ORE and R versus NR comparisons is far from demonstrating that all charges levied against the model are misguided (e.g., Lovejoy, 1968; Mackintosh, 1965).

[3] A casual survey of colleagues showed a perfect split on the designation of this conventional term, with most of them unaware of its ambiguity.

The authors think the model as stated does encounter serious difficulties with certain kinds of results (e.g., on cue blocking, overshadowing, learned distinctiveness of cues), but a review of that evidence and possible theoretical emendations is too far afield for the present note.

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