4. INSTRUCTIONAL APPLICATIONS 1

Chaired by Margaret Anderson, *State University of New York*

Teaching the Rescorla-Wagner model using STELLA-II

VIRGINIA BLANKENSHIP, STEPHEN S. SCHORIE, ANGELA J. SHAW, and JUSTIN TUMLINSON
Northern Arizona University, Flagstaff, Arizona

Although the Rescorla-Wagner model is widely taught in learning courses, most textbooks present a simplified version that does not contain all of its parameters. On the basis of Rescorla and Wagner (1972) and the Turbo PASCAL program by Lachnit, Schneider, Lipp, and Kimmel (1988), we created a simulation using STELLA-II, an icon-based program by High Performance Systems, Inc. We argue that this simulation facilitates teaching the complete Rescorla-Wagner model. Using trans-switching (Kimmel & Ray, 1978; Lachnit, 1986; Murrin & Kimmel, 1986) as an example, we demonstrate the effectiveness of the STELLA-II version of the Rescorla-Wagner model as a heuristic tool.

Although the (1972) Rescorla-Wagner model of classical conditioning is widely taught in undergraduate and graduate courses in learning, most textbooks present a simplified version of the model, which does not contain all of its parameters (cf. Domjan, 1993; Klein, 1991; Lieberman, 1993; Schwartz & Reisberg, 1991; Wilhite & Payne, 1992). These textbooks reduce the model to a relationship that includes only the rate of association (c), the associative strength (V), the asymptotic level (λ), and the change in associative strength (ΔV). Missing are the salience of the stimuli (α), the rate parameter for reinforcement and nonreinforcement (β), and the proportion of reinforced trials for the background and the conditioned stimulus, or CS (π) (Rescorla & Wagner, 1972). Lachnit, Schneider, Lipp, and Kimmel (1988) have simulated the complete model using Turbo PASCAL, but few students have the programming expertise to fully understand their simulation. Using STELLA-II, a product of High Performance Systems, Inc., we have developed an icon-based simulation that we believe facilitates the teaching of the full Rescorla-Wagner model. The icons make it easy for students to visualize what is going on in the model and should help them grasp the model in its entirety. Further, we believe that the icon-based model provides a heuristic tool for understanding the implications when the Rescorla-Wagner model is applied to more complicated procedures, such as transswitching.

STELLA-II

Currently available for the Macintosh computer,¹ STELLA-II is a model-building program that can provide a visual representation of theories that are stated mathematically and/or logically. The program has three basic units—stocks, inflows, and converters—that can be connected and programmed to produce simulations.

Stocks can be denoted as reservoirs, queues, conveyors, or ovens. Reservoirs accumulate values based on inflows and outflows, queues control the flow of items that back up behind a limited outflow, conveyors transport items based on a transit time, and ovens simulate the control of processes that require a certain amount of time to complete. Inflows are used to represent the rate at which reservoirs are filled, the rate at which items stack up in queues, the amount of material to be conveyed from one place to another, and the amount of product that is available for processing in an oven.

Converters operate on inflows and on each other (see Figure 1). Connectors (arrows) from reservoirs, inflows, outflows, and from other converters pass values to the converter. Outputs are then calculated on the basis of the logical and mathematical algorithms programmed into the converter. Converters can take input from reservoirs, but they cannot provide input to reservoirs; only inflows can fill reservoirs.

In addition to connectors passing values from one parameter to another, ghosts can be created from the icons, creating duplicates of parameters in various regions of the diagram (program), thereby making the diagrams more orderly and easily understood.

STELLA-II contains built-in logical functions, such as IF, THEN, ELSE, AND, OR, and NOT, and built-in mathematical functions, such as LOG10, MOD, SQRT,

We would like to thank Randi Reppen for her editorial assistance. Address correspondence to V. Blankenship, Department of Psychology, Northern Arizona University, P.O. Box 15106, Flagstaff, AZ 86011.

Figure 1. STELLA-II icons.

and MAX. It also has built-in trigonometric, discrete, and statistical functions. A number of special functions are also available. For example, SWITCH returns a value of 1 if its first argument (input 1) is greater than its second argument (input 2); otherwise, a value of 0 is returned.

Once a model has been constructed, STELLA-II provides for graphical, tabular, and animated output, which allows the viewer to see what happens to the parameter values in simulated "real" time. Changes in the model are easily programmed by clicking in order to go behind the icon and change its definition or its initial value.

The Rescorla-Wagner Model

On the basis of the model of classical conditioning, as described in Rescorla and Wagner (1972, pp. 86-93), we have created a simulation using STELLA-II that can be used for teaching the model in undergraduate and graduate classes. The reservoirs in the Rescorla-Wagner model represent the strength of association (V) and the inflows represent the change in association (ΔV) calculated for each trial. Alpha, beta, lambda, and pi are converters that operate upon each other or upon the inflows.

The model can best be conceptualized as two reservoirs, one representing the strength of association (V) for the background (A), and the other representing the V for the CS (X) and the background—a compound stimulus referred to by Rescorla and Wagner as AX . The V for X (represented by a converter) is calculated as the V for AX minus the V for A .²

In the upper part of Figure 2, the parameters alpha, beta, lambda, and pi are represented by converters. In the bottom part of the figure, ghosts of the two reservoirs are used to calculate the V for X . On the top left-hand side of the figure, a random-number generator is used to determine whether a trial is an A trial (just the background) or an AX trial (CS with background). Following Rescorla and Wagner (1972, p. 88), one fifth, or 20% of the trials are determined to be AX trials. This is accomplished by setting a cutoff at .20. If the random number, constrained to values between 0 and 1.0, is less than .20, the trial is declared an AX trial; otherwise, it is an A trial. If it is an A trial, the alpha for A is set at .1, the salience for the background; otherwise, the salience, or alpha, for A is 0. If the trial is an AX trial, the alpha for X (or for the compound AX) is set at .5 (five times the salience for the background); otherwise, the alpha for X is set at 0.

Shown on the right-hand side of Figure 2 are the parameters that determine reinforcement. Pi for A and pi

for X are successively set to the combinations of values depicted in Figure 7 of Rescorla and Wagner (1972, p. 89). A second random-number generator determines whether or not reinforcement is applied for a particular trial. (Just one random-number generator is needed because on each trial one of the alpha values will be set to 0, and, as will be explained later, the entire value of ΔV for A or AX on that trial becomes zero.) If pi for A or pi for X is less than the random number, reinforcement is applied and beta is set to .1—the value proposed by Rescorla and Wagner. Otherwise, beta for that trial is set to .05 for nonreinforcement.

The value of lambda on each trial also depends upon whether the trial is determined to be reinforced or not. On a reinforced trial, lambda becomes 1.0; on a non-reinforced trial, lambda becomes 0.

Now we are ready to put both sides together and determine the calculation of ΔV . Following Rescorla and Wagner, ΔV is the product of alpha times beta times the difference between lambda and the current associative value, V [i.e., $\Delta V = \alpha \cdot \beta \cdot (\lambda - V)$]. The set of curves generated by the model for the combination of pi values in Rescorla and Wagner's Figure 7 is shown in the present Figure 3.

Transswitching

We believe that when students learn the Rescorla-Wagner model using the icon-based simulation, they will be able to understand more fully the parameters that affect conditioning and will be able to understand the experimental tests of the model that utilize alpha, beta, and pi. For example, an appreciation of the controversy surrounding transswitching (Furedy, 1991; Kimmel & Lachnit, 1988, 1991; Lachnit & Kimmel, 1991; Lovibond, 1991; Martin & Levey, 1991) requires an understanding of the complete Rescorla-Wagner model.

Transswitching is a phenomenon that was first identified in Pavlov's laboratory and was subsequently described by Konorski (1939, cited in Kimmel & Ray, 1978); dogs that had been repeatedly conditioned in various settings exhibited unusual conditioned responses (CRs). Asratyan (1961, 1965, cited in Kimmel & Ray, 1978) developed an experimental paradigm to create transswitching. As described by Kimmel and Ray,

A dog would receive classical pairing of a conditioned stimulus and food in experimental chamber A, for example, and classical pairing of the same conditioned stimulus with shock in experimental chamber B. Under this experimental regimen, the animal acquired a conditioned appetitive response (e.g., salivation) to the conditioned stimulus in chamber A and a conditioned defensive response (e.g., flexion) to it in chamber B. (p. 189)

The two different backgrounds served as discriminative stimuli to elicit different CRs to the same CS.

Transswitching came to be defined as the repeated conditioning of an animal or a human with two tonic CSs (e.g., the chambers) and a single phasic CS (e.g., the food; see Figure 4). Various CSs have been used (auditory and visual), but a typical transswitching experiment

Figure 2. STELLA-II version of the 1972 Rescorla-Wagner model of classical conditioning: Associative strength (V) for CS (X) against a background (A).

is described by Lachnit (1986), who used two tonic CSs (auditory CSs of 400 and 1400 Hz) and a single phasic CS (a visual stimulus of a white circle projected in front of the subject's face). The terms *tonic* and *phasic* do not refer to the modality of the CS, but to the length of time that it is on. In Lachnit's experiment, the tonic CSs were on for 4-6 min, and the phasic CS was intermittently available for 5 sec while the tonic CS stayed on. Seven segments were presented, with 1-min time-outs between

the segments. The two tonic CSs operated like discriminant stimuli in operant conditioning, because the same phasic CS was always followed by the US (shock) when one tonic CS was on, but was never followed by the US when the other tonic CS was on. In human models of transswitching, physiological indicators of arousal were measured during the tonic and phasic CSs.

Originally, it was assumed that conditioning would first occur to the tonic CSs and that once a reliable CR had

Figure 3. Graphical output from STELLA-II, showing associative strength (V) for CS (X) for five different combinations of proportions of reinforcement (pi) for AX and A. Line 1 (top) shows V for X with pi for AX = .8 and pi for A = 0; Line 2, V for X with pi for AX = .8 and pi for A = .4; Line 3, V for X with pi for AX = .8 and pi for A = .8; Line 4, V for X with pi for AX = .2 and pi for A = .8; and Line 5, V for X with pi for AX = 0 and pi for A = .8.

Figure 4. Sequence of events in a typical transswitching experiment.

been established to the tonic CSs, conditioning would be established with the phasic CS. However, recent experiments with humans indicate that the phasic conditioning is first established differentially (termed *phasic differentiation*), usually in the first conditioning session. Tonic differentiation, or differential CRs to the two tonic CSs, comes later; in fact, in other studies it has taken two experimental sessions separated by 48 h to establish tonic differentiation (see Kimmel & Ray, 1978; Lachnit, 1986; Murrin & Kimmel, 1986).

Using STELLA-II, we have extended the Rescorla-Wagner model to simulate the transswitching preparation (Kimmel & Ray, 1978; Lachnit, 1986; Murrin & Kimmel, 1986). The tonic portion of the experiment is a background for the phasic portion, but another background is also interspersed between the tonic portions—the time-outs. Subjects are brought into the laboratory, hooked up to various physiological measuring devices, and then given two tonic CSs punctuated with a single phasic CS interspersed with periods of *no CS*. The background, A, then, should be defined not as the tonic CSs, but as the true background, the experimental room, the equipment, the experimenter, and any other sundry stimuli in the experimental situation. Each period of time during which the tonic CS is presented is both an AX trial against the A background of the experimental situation and the A background for the AX trial with the intermittent phasic CS.

Figure 5 includes five reservoirs, V for Background A (the experimental situation), V for Tonic 1 plus Background A, V for Tonic 2 plus Background A, V for Tonic 1 plus Phasic plus A, and V for Tonic 2 plus Phasic plus A. At the bottom of the diagram, Tonic 1, Tonic 2, Phasic 1, and Phasic 2 have been defined in each case as the difference between the strength of association for the phenomenon named, plus its background (compound stimulus), minus its respective background. Specifically:

$$\begin{aligned}\text{Tonic 1} &= V_{\text{for_Tonic_1_plus_Background_A}} - V_{\text{for_Background_A}} \\ \text{Tonic 2} &= V_{\text{for_Tonic_2_plus_Background_A}} - V_{\text{for_Background_A}} \\ \text{Phasic 1} &= V_{\text{for_Tonic_1_plus_Phasic_plus_A}} - V_{\text{for_Tonic_1_plus_Background_A}} \\ \text{Phasic 2} &= V_{\text{for_Tonic_2_plus_Phasic_plus_A}} - V_{\text{for_Tonic_2_plus_Background_A}}\end{aligned}$$

Another strength of the STELLA simulation program is the facility it offers for assigning successive values to a variable by using the graph function behind the icon. For example, the converter `Type_of_Trial` was defined in rela-

tionship to time by choosing the option to make this parameter a graph. The value 0 for `Type_of_Trial` was defined as Background A trials, the value 1 defined as Tonic 1 plus Background A trials, the value 2 defined as Tonic 1 plus Phasic plus Background A, the value -1 defined as Tonic 2 plus Background A, and the value -2 defined as Tonic 2 plus Phasic plus Background A trials. For the 150 time units of the simulation, the value of `Type_of_Trial` was set from time units 0-10 at 0 (setting up the experiment), 11-20 as alternating 1 and 2 (Trial 11 was set to 1; Trial 12 to 2; Trial 13 to 1, etc.) to represent the first tonic and phasic trials to be reinforced, 21-25 set to 0 (time-out), Trials 26-35 alternating -1 and -2 (second tonic and phasic trials without the US), Trials 36-40 at 0 (time-out), Trials 41-50 alternating 1 and 2 again, and so on. This resulted in a simulation of an initial time-out, alternating tonic and phasic trials reinforced, time-out, alternating tonic and phasic trials nonreinforced, time-out, and so on.

Correspondingly, on the left side of Figure 5, the `When_Reinforced` converter was also made into a data file or a graph based on time. Reinforcements were assigned to time units 12, 14, 16, 18, and 20, to time units 42, 44, 46, 48, and 50, and to the other alternating time units of the Phasic 1 trials. On reinforced trials, beta for all the modules, A, T1 A, T2 A, T1 P A, and T2 P A, are set to .1; on nonreinforced trials, beta is set to .05. (Remember from the original Rescorla-Wagner simulation that when the trial is not an A or a T1 A trial, for example, the alpha for that trial equals 0, and the entire product for ΔA or $\Delta T1 A$ becomes 0.) Lambda, of course, is 0 for nonreinforced trials and 1.0 for reinforced trials.

Now we can see clearly the dilemma of the transswitching paradigm. $\alpha_{\text{for_A}}$ is clearly a value greater than 0 when `Type_of_Trial` equals 0, and 0 otherwise. $\alpha_{\text{for_T1_P_A}}$ and $\alpha_{\text{for_T2_P_A}}$ are greater than 0 when `Type_of_Trial` equals +2 and -2, respectively, and 0 otherwise. But when are the values of $\alpha_{\text{for_T1_A}}$ and $\alpha_{\text{for_T2_A}}$ greater than 0? If they are greater than 0 only when `Type_of_Trial` equals +1 and -1, respectively, then they never get reinforced and we get the same results that Kimmel and Lachnit (1986) obtained—no tonic differentiation. If, however, we recognize that the tonic CSs are the background for the phasic CS and the foreground for the experimental situation, then we would want the value of $\alpha_{\text{for_T1_A}}$ and $\alpha_{\text{for_T2_A}}$ to have values greater than 0 anytime that `Type_of_Trial` was greater than 0 (for Tonic 1) or less than 0 (for Tonic 2). That is, the tonic CS is still on when the phasic CS comes on, and Tonic 1 should get reinforced just as Phasic 1 does.

Using the logic of Rescorla and Wagner's treatment of pi values for A and AX in their 1972 article, it seems reasonable that $\alpha_{\text{for_T1_A}}$ and $\alpha_{\text{for_T2_A}}$ should be greater than 0 anytime the tonic CS is on. Figure 6 is the graphical output of a simulation using alpha values of .02 for A, .1 for T1 A and T2 A, and .5 for T1 P A and T2 P A. (Following Rescorla and Wagner

Figure 5. STELLA-II version of the transswitching preparation based on the 1972 Rescorla-Wagner model of classical conditioning.

[1972, p. 88] in each case, the salience of the background is one fifth of the foreground.) Assigning values to the saliences of the tonic CSs that are less than the values assigned to the phasic CS is suggested by Kimmel and Lachnit (1988) and makes more sense given this analysis of the experimental situation.

Using the STELLA-II model, undergraduates can try out other parameter values and demonstrate for themselves why changing the beta values does not result in demonstrating tonic differentiation—a solution proposed by Bond

and Siddle (1988) and refuted by Lachnit and Kimmel (1991). Lachnit and Kimmel repeatedly warn that parameter changes to the Rescorla-Wagner model do not always result in the outcomes predicted by intuitive extension of the model, and only by running a simulation can the implications of such a change be recognized. We believe that using an icon-based simulation such as STELLA-II makes the full model more accessible to students and researchers alike, and that the visual understanding of the model and the ease with which values can be

Figure 6. Graphical output from STELLA-II showing the two tonic CRs and two phasic CRs.

changed will provide a heuristic tool to expose the limitations of the model and to provide support for it, such as the example presented above for transswitching.

We further believe that STELLA-II can provide teachers and students with a mechanism for exploring other theories of learning and motivation. For example, we have simulated the Lorenz model of instinctual behavior (Lorenz, 1950) and have used the STELLA-II capacity for animation to set the model in motion. By watching the reservoirs fill and empty in response to switches turning on and off, students have come to understand more fully the implications of this dynamic model. We have also used STELLA-II to simulate the Atkinson and Birch (1970) dynamics of action model for use as a teaching tool (Blankenship, Tumlinson, & Sims, 1993). We envision a laboratory course in computer simulations to accompany psychology classes, which would utilize STELLA-II in order to give students experience in model building.

REFERENCES

- ATKINSON, J. W., & BIRCH, D. (1970). *The dynamics of action*. New York: Wiley.
- BLANKENSHIP, V., TUMLINSON, J., & SIMS, M. A. (1993). *Teaching and research simulations of the Atkinson and Birch dynamics of action model*. Unpublished manuscript.
- BOND, N. W., & SIDDLE, D. A. T. (1988). Human Pavlovian conditioning: Commentaries. *Biological Psychology*, 27, 185-190.
- DOMJAN, M. (1993). *Domjan and Burkhard's The principles of learning and behavior* (3rd ed.). Pacific Grove, CA: Brooks/Cole.
- FUREDY, J. J. (1991). On testing current cognitive theories of Pavlovian conditioning in the human Pavlovian autonomic transswitching preparation. *Biological Psychology*, 32, 201-204.
- KIMMEL, H. D., & LACHNIT, H. (1988). The Rescorla-Wagner theory does not predict contextual control of phasic responses in transswitching. *Biological Psychology*, 27, 95-112.
- KIMMEL, H. D., & LACHNIT, H. (1991). On extension of Rescorla-Wagner model. *Biological Psychology*, 32, 211-213.
- KIMMEL, H. D., & RAY, R. L. (1978). Transswitching: Conditioning with tonic and phasic stimuli. *Journal of Experimental Psychology: General*, 107, 187-205.
- KLEIN, S. B. (1991). *Learning: Principles and applications* (2nd ed.). New York: McGraw-Hill.
- LACHNIT, H. (1986). Transswitching and contextual conditioning: Relevant aspects of time. *Pavlovian Journal of Biological Science*, 21, 160-172.
- LACHNIT, H., & KIMMEL, H. D. (1991). Extending the Rescorla-Wagner theory to account for transswitching. *Biological Psychology*, 32, 193-200.
- LACHNIT, H., SCHNEIDER, R. L., LIPP, O. V., & KIMMEL, H. D. (1988). RWMODEL: A program in Turbo Pascal for simulating predictions based on the Rescorla-Wagner model of classical conditioning. *Behavior Research Methods, Instruments, & Computers*, 20, 413-415.
- LIEBERMAN, D. A. (1993). *Learning: Behavior and cognition* (2nd ed.). Pacific Grove, CA: Brooks/Cole.
- LORENZ, K. (1950). The comparative method of studying innate behavior patterns. In *Physiological mechanisms in animal behaviour* (Society for Experimental Biology, Symposium No. 4, pp. 221-268). New York: Academic Press.
- LOVIBOND, P. F. (1991). "Extending the Rescorla-Wagner theory to account for transswitching": Reply. *Biological Psychology*, 32, 205-207.
- MARTIN, I., & LEVEY, A. B. (1991). "Extending the Rescorla-Wagner theory to account for transswitching": Comment. *Biological Psychology*, 32, 209-210.
- MURRIN, M. R., & KIMMEL, H. D. (1986). Determinants of tonic and phasic reactions in transswitching. *Pavlovian Journal of Biological Science*, 21, 117-123.
- RESCORLA, R. A., & WAGNER, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and non-reinforcement. In A. H. Black & W. F. Prokasy (Eds.), *Classical conditioning II: Current research and theory* (pp. 64-99). New York: Appleton-Century-Crofts.
- SCHWARTZ, B., & REISBERG, D. (1991). *Learning and memory*. New York: Norton.
- WILHITE, S. C., & PAYNE, D. E. (1992). *Learning and memory: The basis of behavior*. Boston: Allyn & Bacon.

NOTES

1. A Windows version was due for release in January 1994.
2. The associative strength of a compound (V for AX) has been defined by Rescorla and Wagner (1972) as the sum of V for A plus V for X: $(V \text{ for } AX) = (V \text{ for } A) + (V \text{ for } X)$. Our simulation presents the derivation of V for X as V for AX minus V for A: $(V \text{ for } X) = (V \text{ for } AX) - (V \text{ for } A)$. This interpretation is inferred from Rescorla and Wagner's analysis of a single CS and its background (1972, pp. 86-90). Simulations of experimental situations combining two CSs that have been previously conditioned separately (as in the overexpectation phenomenon) would involve adding the individual associative strengths to compute the compound strength. The case of a single CS and its background differs from the overexpectation phenomenon because the CS never occurs without the background.