CHAPTER 8

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I. The Cause of Short-term Behavioral Adaptation

A. Classes of Causal Machinery

1. Contiguity

At first observation, the most salient prerequisite of conditioning is the simple pairing of the CS with the US. This class of explanation asserts that the temporal proximity of an antecedent event such as a CS or a response with a subsequent outcome such as meat powder or food presentation is the cause of learning. For example, bell-meat powder, bell-meat powder, bell-meat powder results in bell-salivation.

a. Contravening Evidence

But meat powder presented with an equal frequency in both the trial stimulus and the intertrial stimulus fails to produce salivation to the bell, for example, bell-meat powder + no bell no meat powder + bell no meat powder + no bell no meat powder results in bell no salivation.

2. Contingency

With further thought, a somewhat more complex arrangement appears to be the prerequisite for learning. It can be labeled with an emphasis on mentalism (e.g., information, good predictor or signal relations) or it can be labeled with an emphasis on the procedure itself: covariance. For example, no bell-no meat powder + bell-meat powder / no bell-no meat powder + bell-meat powder / results in no bell-no salivation and bell-salivation.

a. Contravening Evidence

But, backward conditioning seems substantially weaker than forward conditioning which undercuts the viability of simple covariance as a cause of conditioning.

b. Rebut

1. Deny contradictory results (e.g., claim results failing to show backward conditioning are measuring the wrong behavior).
2. Deny contradictory procedure (e.g., claim the backward conditioning procedure has been confounded.
3. Deny contradiction (claim the results of evolution are such that special cases emerge. Those animals that showed backward conditioning had less reproductive success.) In this case, it would simply be argued that there is no reason to believe that backward conditioning would be equivalent to forward conditioning.

3. Rapprochement

The contingency model can simply declare that backward correlations don't work as well as forward (at least) in controlling the behavior appropriate to the period immediately preceding the reinforcer. Besides, contingency is produced by contiguity (events occurring together), so conflict between contiguity and contingency is more apparent than real and the failure to find very strong backward conditioning does not represent a very serious challenge to the predictive power of a contingency view.

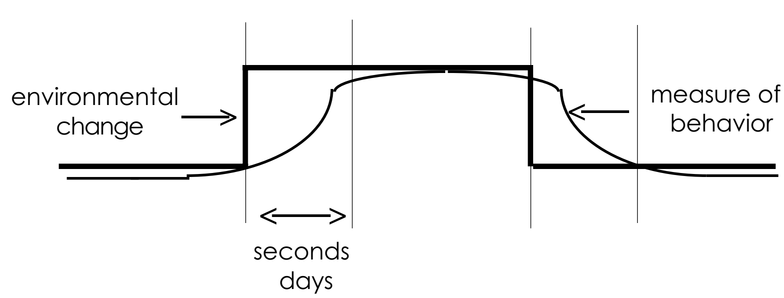
B. Contingency and Short-term Adaptation

The contingency view argues that short-term behavioral adaptation is most appropriately seen as caused by the procedures which produce that time scale effect. It is the exposure to the elements of a contingency between events that causes short-term behavioral adaptation. The contingency is between antecedent events and subsequent states.

The focus of the contingency view is away from reductionistic internal events and away from other time scales of adaptation and towards the actual procedures which cause the adaptation of interest.

1. Event Diagram of Contingency and Behavioral Adaptation

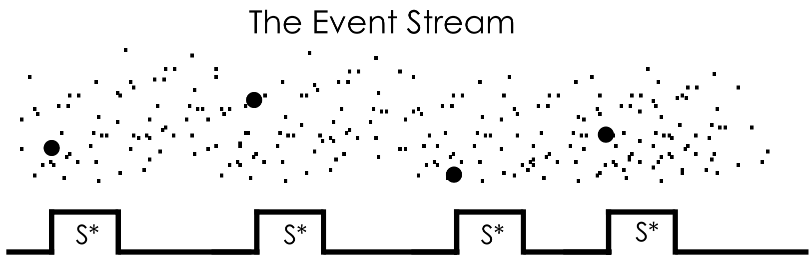
Recalling our original depiction of behavior adaptation:



and reiterating that the environmental change (represented by the thick solid line) represents a change in a contingency not simply the occurrence of a stimulus.

2. The Event Stream

Typically, if some specific event (response or stimulus) consistently and differentially occurs immediately before a functionally significant event (reinforcer) and not otherwise it becomes conditioned (illustrated below by the big dots, which occur immediately before the reinforcer but not otherwise). Other events (other dots) which have a random relationship with the reinforcer (i.e., occasionally occur with the reinforcer, and occasionally occur without the reinforcer) do not become conditioned.



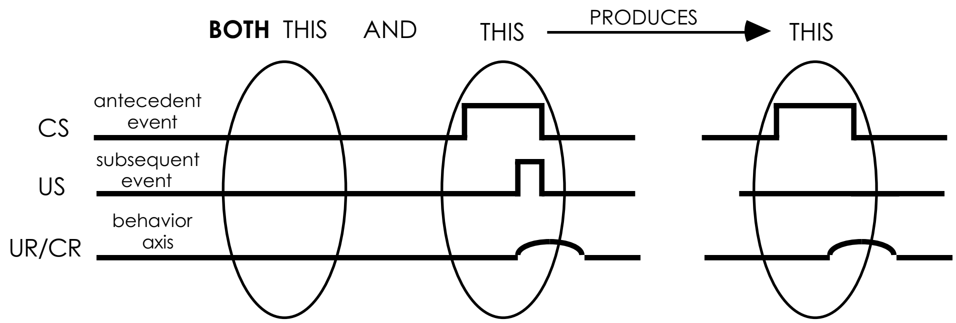
a. Environmental Events Are Actually Environmental Changes

Typically, events are discussed as if they occurred against a background of absolutely nothing. This is an oversimplification. There is always a stimulus present, there is always a behavior occurring, and there is always some contingency in place. Most technically, only stimulus changes occur, only behavior changes occur, and only contingency changes occur.

3. Example Paradigms

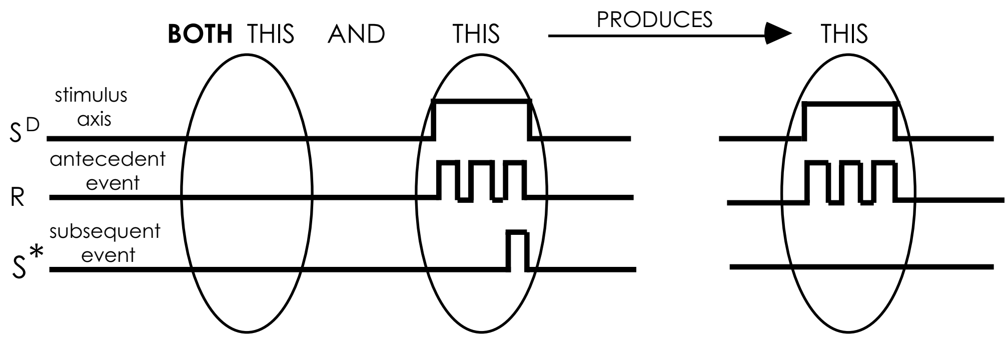
a. The Reflex Conditioning Case

The following figure recalls that the relevant environmental change is a change in the contingency of an explicit antecedent stimulus and an explicit functionally important outcome (no CS with no US and CS with US). As the result of this contingency, the arbitrary antecedent stimulus comes to control a response.



b. The Operant Conditioning Case

The following figure previews that the contingency of a stimulus context, a response, and an explicit functionally important outcome, is responsible for operant conditioning.



4. Contingency

The causal (and explanatory) contingency can be illustrated in the following figure.

Subsequent Outcome		A	B
	D	these conjunctions are absent	these conjunctions occur
	C	these conjunctions occur	these conjunctions are absent

Antecedent Event

Behavioral adaptation implies two or more antecedent events (A and B), two or more subsequent outcomes (C and D), a reliable relationship between the elements (A with C, and B with D), and exposure to more than one conjunction (both A/C and B/D). (These are the "big four.") This notation is applicable for S-S* contingencies and for R-S* contingencies.

a. Elements Making up a Contingency (the "big four")

Simply put, exposure to a systematic relationship of differences in antecedents and outcomes, produces a systematic difference in behavior.

i. Antecedent Events

Such as bell and no bell or lever press and no lever press, or even a continuous series of tones ranging from high to low tones or the passage of time. The antecedents must be capable of being discriminated (i.e., >= 1 JND). Presumably, the more similar the antecedent stimuli, the longer it will take the contingency to come to control differentiated behavior.

ii. Subsequent Outcomes

Such as meat powder and no meat powder or food access and no food access, or even a continuous gradient of warmth ranging from warm to cold, or from too hot to too cold for that matter. The outcomes must also be capable of being discriminated (i.e., >= 1 JND).

In the case of food - no food, a prerequisite is food deprivation, otherwise the two outcomes would not be different. Operations which establish the distinction between the subsequent outcomes are labeled establishing operations. Note that an animal can satiate over the course of a session. In that case, the contingency would change over the course of the session. Presumably, the more similar the subsequent outcomes, the longer it will take a contingency to come to control differentiated behavior.

iii. Reliable Relationship

Bell with meat powder, no bell with no meat powder. Lever press with food, no lever press with no food. Higher tones with more warmth and lower tones with less warmth.

iv. Exposure to Alternatives

The animal must be exposed to both conjunctions not to just one, (or a range of pairs of higher and lower tones with more and less warmth.)

b. Dichotomous Versus Continuous Contingencies

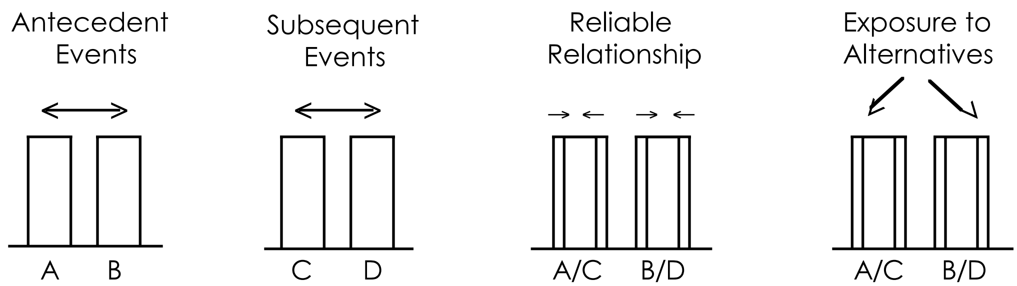
As could be inferred from the previous examples, contingency can be between any combination of dichotomous or contiguous antecedent events and subsequent outcomes.

i. Dichotomous 2 x 2 Contingency

In the dichotomous case, there are two antecedent events which have a reliable relationship with two subsequent outcomes and the organism is given exposure to both of both.

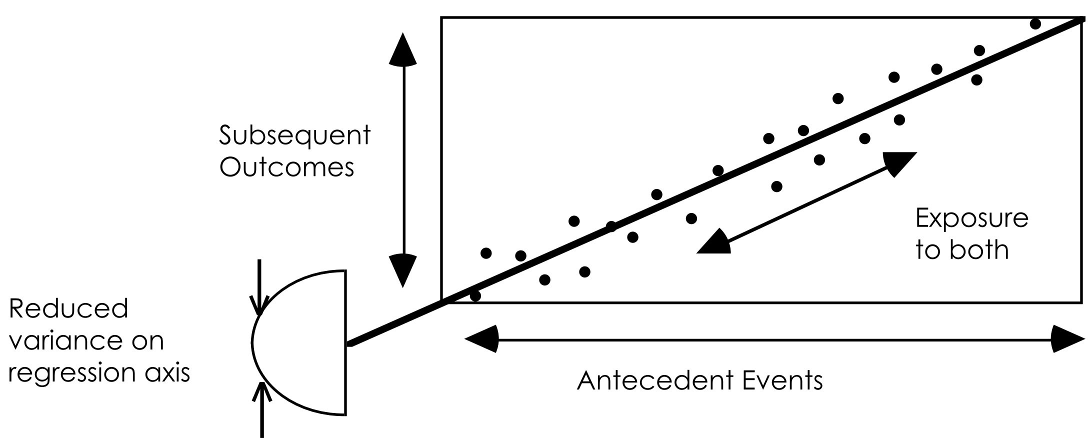
		Antecedent Event: A	Antecedent Event: B
Subsequent Outcome	D	these conjunctions are absent	these conjunctions occur
Subsequent Outcome	C	these conjunctions occur	these conjunctions are absent

The following figure illustrates the four elements involved in a contingency of dichotomous events.



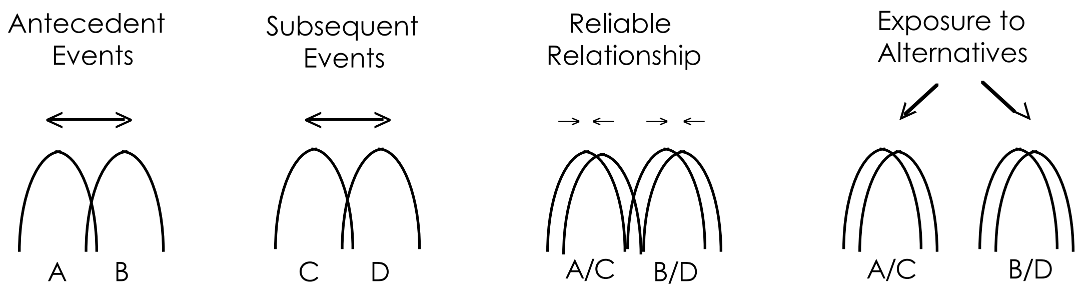
ii. Continuous Contingency

In this second more general case, many values along the antecedent events ("AB") dimension and many events along the subsequent outcome ("CD") dimension exist, and these show covariance. For example, A1 with C1, A2 with C2, ..., B99 with D99.



(1) Intermediate Example

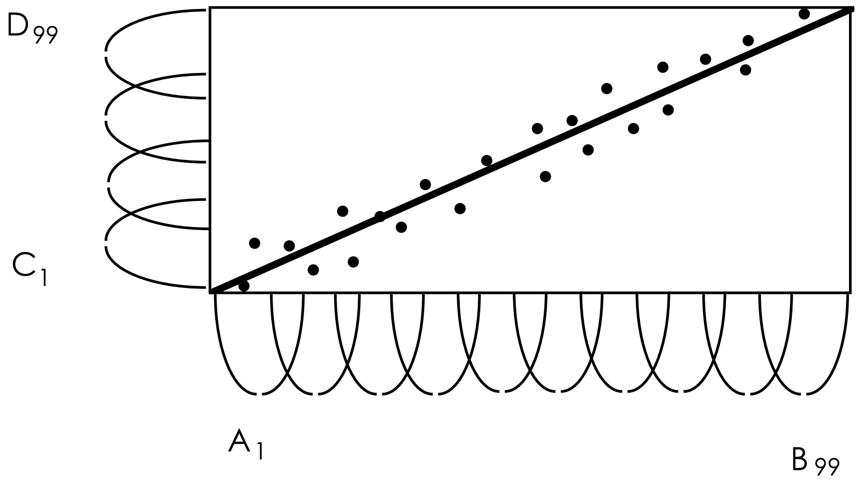
The continuous range of events in the above scatter plot figure can be easily illustrated by way of an intermediate example. First rather than truly dichotomous events such as light on and light off, we could consider that we have a normally distributed set of intensities centering on A(C) and a normally distributed set of values centering on B(D). In this case, there is some overlapping values between A and B (C and D).



This intermediate example provides a more realistic picture than the dichotomous contingencies table in the previous section and makes more obvious the bridge to signal detection theory as a conceptualization for stimulus differences. Signal detection theory provides a productive conceptual framework for understanding "reaction to" two situations when one dimension such as light intensity is actually two different but overlapping distributions and the subsequent outcome is dichotomous because there is a correct response and an incorrect response. The two distributions could be anywhere on a continuum from easy to difficult to distinguish. Two events such as bright lights on or off would be very distinct. In that case, the two distributions would be non overlapping like the dichotomous example given previously. Alternatively, the two "events" could be elements from two distributions that are almost identical.

(2) General Case

In the most general case (continuously distributed x axis with continuously distributed y axis), there would be a single continuum of values along each axis. In that case, the best simplistic representation would be a whole series of distributions 1 JND apart along each axis (e.g., A_1, A_2, A_3 ..... through B_{99} and C_1 ..... D_{99}). In that case, there would be multiple "decisions" along each axis (e.g., A16 from A15 and A17, and C16 from C15 and C17). A16 would then be paired with C16 with a level of reliability determined by the discriminability of the x and y axes and the correlation of the x and y axes.

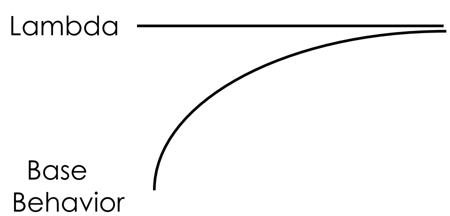


In principle, the AB and CD continuum could be nonlinear (light intensity) or bipolar (e.g., from too hot, to just right, and on to too cold). The obtained behavior controlled by the AB dimension would reflect its nature and discriminability, the nature and discriminability of the CD dimension, and the behavior appropriate for each of those conjunctions.

5. Behavioral Adaptation to a Contingency

Nature provides experiences with conjunctions of antecedent events and subsequent outcomes (i.e., evolution, development, and learning put in "dots" in a "scatter plot" contingency space.) Adaptive behavior is a minimizing function. The obtained behavior is the "line" that "integrates" the dots or that minimizes the "sum of the squared differences" between them. In the same way the regression line "falls" down to the point of minimum squared differences, the behavioral vector "falls" down to an appropriate reaction to the experiences.

The general notion is that exposure to a contingency moves behavior toward some limit or lambda and that that lambda is established by the history of that animal. The asymptotic limit or equilibrium for short-term adaptation is established via medium- and long-term adaptation. Obvious examples of long-term effects would be approach to food and avoidance of shock.

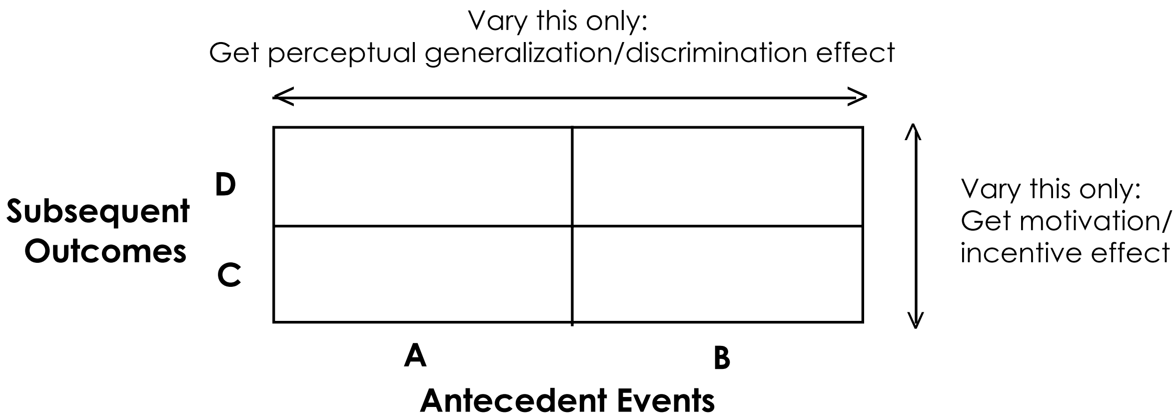


Being surprised by or being unprepared for an outcome could be seen as variance in the behavior appropriate for an outcome. Short-term behavioral adaptation or learning is seen as the result of a reduction in the "unaccountable" variance in the behavior produced by various experienced outcomes. When that behavioral variability is reduced relative to the variance of the behavior in the absence of a correlated antecedent stimulus, then a behavior change which will show short-term hysteresis occurs (i.e., learning). It is the decrement in the discrepancy between the evolutionarily- and developmentally-established ideal behavior and the current behavior which accounts for the asymptotic decrements in learning. This view accounts for the time course of learning, blocking, and even overshadowing, in that overshadowing would be seen as blocking implemented across long-term adaptation. In the same way that prior ontogenetic experience with a stimulus results in that stimulus blocking conditioning to some new stimulus; prior phylogenetic experience with a stimulus results in that stimulus overshadowing conditioning to some new stimulus.

Long-term equilibriation itself could be seen as asymptotically falling to the constraint set by physics, chemistry, and biology. For example, in trying to establish a behavior in a gene pool (e.g., pigs that could fly) we would be limited by what was possible in physics and chemistry and biology. In the flying pigs example, the presumption would be that it would be unlikely that we could shape flying faster than the speed of light, and that it would be unlikely that components of a living pig could truly spin like a propeller or jet engine, so that acquisition of flapping wings and loss of weight would be plausible necessities. It would be similarly obvious that we could not shape flying without the animal ending up consuming sufficient food to support the high energy behavior. In fact, the range of possibilities are relatively well understood by knowing the energy processing capacity of organic systems, the cube square law, and the laws of aerodynamics.

6. Conceptual Context for Procedures Resulting in Nonassociative Behavior Change

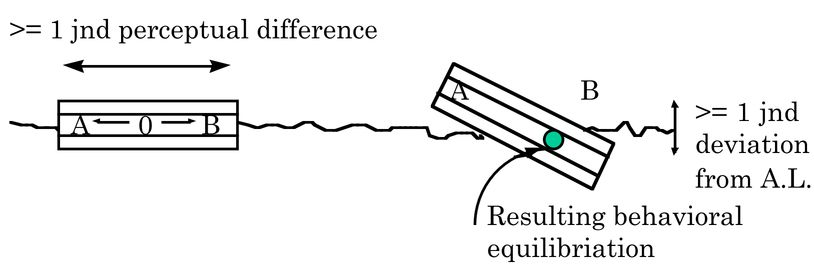
Changes on either of the dimensions (AB or CD) alone do not cause a short-term adaptation (short-term hysteresis at onset and offset). Simple variation in the antecedent event axis, such as the key stimulus for example, produces a generalization/discrimination effect. This is considered instantaneous time scale or a perceptual effect. Similarly, simple variation in the consequence axis without a contingency produces an instantaneous time scale effect generally categorized as an “incentive,” “motivation,” or “arousal” effect.

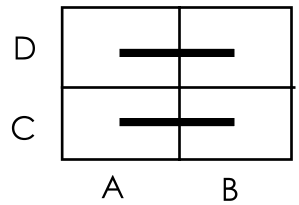


7. Metaphor for Associative Behavioral Adaptation Resulting from a Contingency

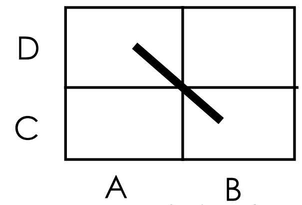
What we label learning is a contingency-produced change in the behavioral equilibrium. The contingency produces the "force" necessary to cause the behavior to adapt. Otherwise, behavior would remain as it was (i.e., "behavioral inertia"). Learning is: 1) a perceptual difference capable of being registered (>= 1 JND); 2) a difference in functionally important subsequent outcomes (>= 1 JND); and 3) behavioral “adjustment” which equilibriates the system. The concept of correlated gradients (AB and CD) removes the necessity of postulating a homunculus in order to explain how information translates to behavior.

A floating hollow wooden pipe containing a bowling ball is a good mechanical metaphor for learning or behavioral adaptation. The metaphor clearly illustrates how an AB difference correlated with a CD difference would result in a equilibrating change (the bowling ball rolls down hill to the end, i.e., behavioral adaptation). A deficit in the metaphor is that it implies that the organism’s adjustment would always be dichotomously one extreme or the other (e.g., respond int he CB box).





Both ends of pipe (A+B)
at same state (C or D)



Two ends of pipe (A+B)
at different states (C or D)

The tipping pipe metaphor illustrates that a homunculus using information to make a decision is unnecessary, as well as obscuring of our real task. Additionally, it illustrates that there is a specific amount of difference which produces the effect, i.e., the JND of the contingency and its constituent elements. If A and B are discriminably different (AB difference) and if C and D are discriminably different (CD difference) and if there is a discriminable correlation (tilt), then a behavioral difference will occur (i.e., the bowling ball will move). Given control and manipulation of any two of the elements, the JND of the third could be determined. This then would be the psychophysics of sensation, the psychophysics of incentive, and the psychophysics of contingency.

8. Metaphor for How Contingencies Can Have a Functional Effect

The mean of random numbers which vary on either side of x, is x. The running total of a large number of tosses of a pair of dice is the total tosses times seven. Electronic signal averagers use the principle that random events sum to the mean times the number of samples in order to cancel random noise from a reliable but weak signal. The constant small bias provided by even very weak signals inexorably inches those counters ahead of the counters tabulating only random signals because for everything that randomness giveth, it also takith away.

Ice sculptures melt leaving behind their wire skeleton. The ice is analogous to the random error which "melts" away toward zero with successive samples. The wire is the real signal which remains because it is immune to the melting toward zero because it's constant "bias" is always there on every sample.

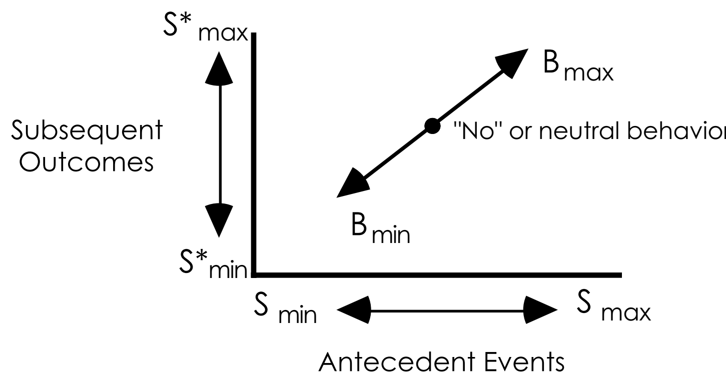
An event's consistent occurrence just before food presentation and not otherwise results in an "associative" effect on the functional relationship between the stimulus and response because they are always there and always get to move "forward," whereas the events which are sometimes just before the reinforcer (D) and sometimes just before the "not reinforcer" (C) sometimes move forward and sometimes move backward.

C. The Bipolar Output of Short-term Behavioral Adaptation

1. Overview

Variations in the subsequent outcome such as: 1) meat powder versus no meat powder or 2) a continuous set of possible outcomes from no meat powder to much meat powder or 3) a series of periods during which food presentation was successively more probable, or 4) a series of successively shorter delays to food presentation, are all defined as continua with S^*_{min} and S^*_{max} as endpoints. Any antecedent event which is correlated with a specific portion of the S^*_{min} to S^*_{max} continuum is conditioned by that contingency. In the case of a continuous set of stimuli, each correlated with some portion of S^*_{min} to S^*_{max} gradient, then the entire set is conditioned. In either case, the thus created or extracted antecedent stimulus gradient is labeled the S_{min} to S_{max} continuum. In the case of temporal conditioning (when S^*_{max} occurs at a fixed time from some marker but no explicit stimuli are correlated with any portion of the $S^*_{min} – S^*_{max}$ continuum), then only "temporal stimuli" form the $S_{min} – S_{max}$ continuum. This is because specific temporal stimuli are correlated with specific portions of the S^*_{min} S^*_{max} continuum but nothing else is. In the case of totally random food presentations (i.e., randomly related time and no explicit stimuli) there can be no $S_{min} – S_{max}$ gradient.

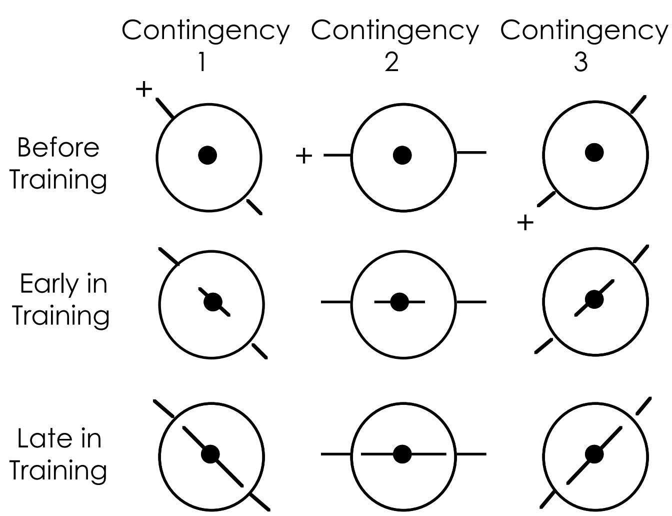
The $S^*_{min} – S^*_{max}$ gradient produces a bipolar gradient of behaviors under the control of the $S_{min} – S_{max}$ gradient because of the contingency between the two gradients. At the extremes, a behavior appropriate to S^*_{max} which comes under control of S_{max} and at the other extreme, a behavior appropriate to S^*_{min} which comes under the control of S_{min}. If there is a correlation across the entire S^*_{min} S^*_{max} gradient, it results in a gradient of behavior appropriate to the S^*_{min} to S^*_{max} gradient under the control of the S_{min} S_{max} continuum. The end points of the behavioral gradient are labeled B_{min} and B_{max}. The two extremes of behavior are akin to mirror images. The stronger the response along one vector (e.g., "approach"), the stronger along the “opposite” vector is created. (e.g., "avoidance"). The measured magnitudes are unlikely to be precisely the same and the behaviors are unlikely to be precisely the opposite, but it may serve some purpose to *define* them as equal and opposite and thereby have some metric of magnitude and vector. The various behaviors along the gradient from B_{min} to B_{max} are the organized sequences of behaviors discussed under “behavior systems” by Timberlake. This perspective explicitly acknowledges the fact that long-term contingencies have established the behavioral limits for the behaviors which occur to the various positions along the S^*_{min} S^*_{max} gradient. In other words, ontogenetic exposure to a contingency produces in the general case: a gradient of behavior from B_{min} to B_{max} with short-term hysteresis. In the simple dichotomous case B_{min} and B_{max} would be the two behaviors controlled by the two stimuli paired with S^*_{min} and with S^*_{max}. A simple example would be pecking a green key associated with food presentation and walking around the chamber during a red key associated with extinction. It is as if the correlation between the antecedent events and subsequent outcomes produce a “valley” along the diagonal between them. The “bowling ball” of behavior rolls back and forth in that valley. More correctly, the positive ball rolls toward max and the negative ball rolls toward min.



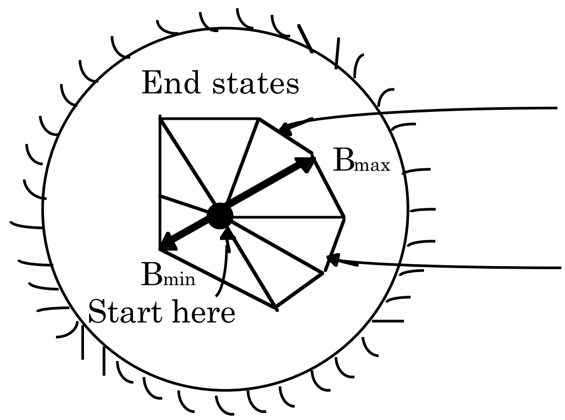
2. Spatial Representations of Continuous Bipolar Behavioral Adaptation

a. Compass Headings Metaphor

Different points along the S_{min} S_{max} continuum control different behaviors. Contingencies with S^*_{min} and S^*_{max} do not produce a simple approach to a location (e.g., going North), while the opposite contingency produces the simple avoidance of that location (e.g., going South). But, **if** various potential behavioral vectors (such as approach and avoidance of one end of an alley) could be represented as various compass headings, then the potential vectors from a “no” behavior or neutral behavior starting point could be represented as a pair of opposing points on a compass. This circular representation is an attempt to depict a whole range of behaviorally opposite vectors. The positions around the circumference are to be considered a nominal scale with opposite behaviors on opposite sides.



Various environmental contingencies

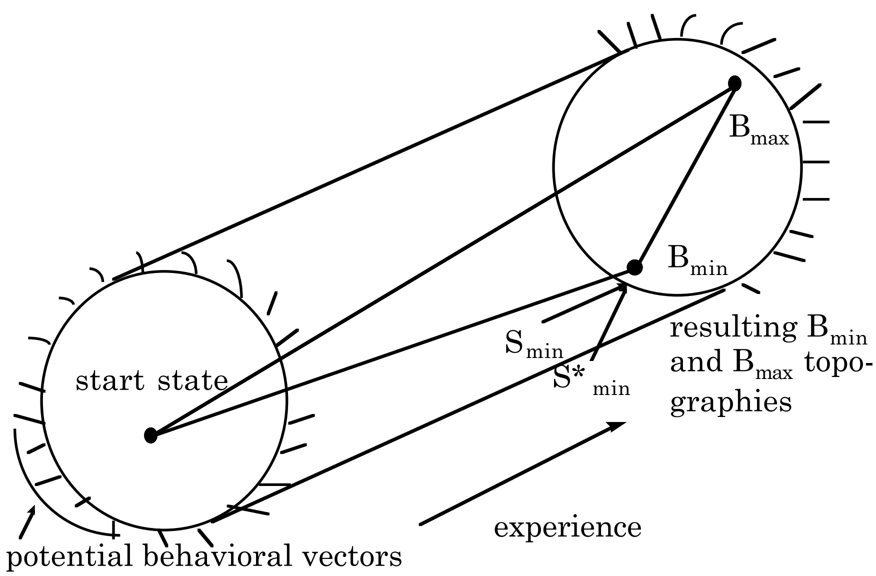


Using this particular representation, we can illustrate the emergence of behavior B_{min} and behavior B_{max}, such that the two are roughly opposite, roughly the same magnitude and could be any of a wide variety of pairs of behaviors which depend on specific contingencies. Evolution and developmental factors set the limits on B_{min} and B_{max} and determines the “appropriate” behavior ("behavior system") for each portion of the constructed S_{min} S_{max} gradient. Note that some other contingency could produce some other B_{min} B_{max} with some other vector (east and west rather than northeast and southwest for example). Both B_{min} and B_{max} emerge from their precursors at roughly the same time. Using the scatterplot metaphor, it’s as if the min and max extremes of the regression line sink deeper into me page and exert a stronger pull on the negative and positive behavior with increasing experience. A second metaphor is that the effect is somewhat like the appearance of the lines in a Bezier curve tool in a computer graphics package, as you pull one end there is an “equal” and “opposite” movement at the other end. B_{min} and B_{max} are the end points (bipolar) produced by the contingency.

Note that there is never a time when the animal acquires a behavior against the background of no behavior whatsoever. Behavior never actually starts at zero or “no” behavior. Rather, the behavior always starts where it was left off by evolutionary, developmental, and prior learning experiences. The single dot is used to represent an origin in the figure that could be equally orthogonal to all the vectors in the present contingency. Secondly, the neutral point of behavior at asymptote is not necessarily where the behavior was when the contingency was put in place.

The next figure adds a third dimension to better depict both the magnitude and vector of behavioral adaptation and the effect of increasing experience. In this case, the figure illustrates various contingencies around a cylinder (like splines) as before. Experience is represented along the axis of the cylinder (from left to right). The behavior start point for both B_{min} and B_{max} is arbitrarily illustrated as a center point on the left end of the cylinder. The establishment of a particular new S^*_{min} to

S^*_{max} would "pull" on the neutral state behaviors and would cause behavioral adaptation with experience. Note that behavior adapts in two ways: one toward the behavior appropriate to S^*_{max} and one toward the behavior appropriate to S^*_{min} and that the behavior has opposing vectors (B_{min} and B_{max}). One behavior B_{max} would be appropriate for the S_{max} S^*_{max} conjunction. A roughly opposite (or at least inhibitory of B_{max}) behavior, B_{min}, would be appropriate for the S_{min} S^*_{min} conjunction.



i. Limitations of the Compass Headings Representation

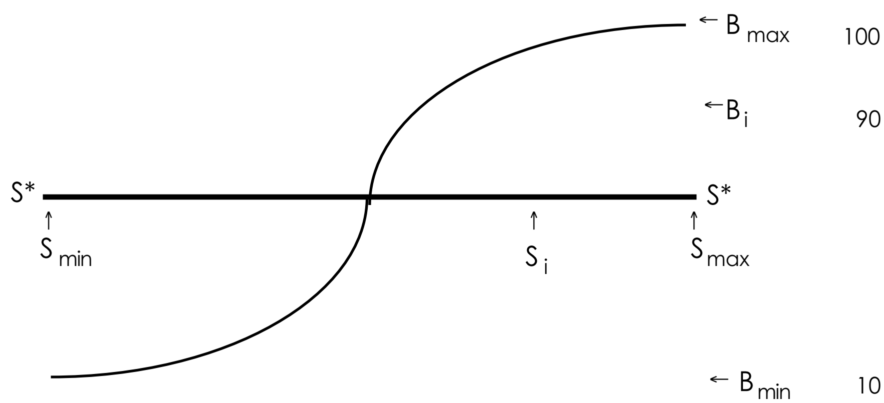
There are several limitations to the preceding schematized environmental contingencies and resulting behavioral adaptation. All possible contingencies do not form a closed circle. For example, if B_{maxB} is to the “left” of B_{maxA}, that does not necessarily mean that B_{minB} will be to the “right” of B_{minA}. Secondly, it is unlikely that the behavioral vectors are equal and opposite. Thirdly, the behavioral start state is not necessarily the same for both B_{min} and B_{max}. The start state is as previously mentioned, where each of the behaviors was left off by previous evolution, developmental and learning contingencies. The establishment of a contingency is never the first contingency, it is always a change from a previous contingency, and the start point would not necessarily be the center point or even on the behavior gradient between B_{min} and B_{max}. Finally, the present scheme simplifies behavior to Behavior A and Behavior not A (or Behavior anti A). A more precise scheme would consider the $B_{min} – B_{max}$ continuum as a series of behaviors such as Behavior A, Behavior B, Behavior C, and Behavior D (i.e., series of behaviors governed by the evoked behavior system.

But, if we ignore the imperfections of the metaphor and simplify the behavioral conceptualization to Behavior A and Behavior Anti A, we can use it for what it helps us with.

b. Two-Dimensional Function

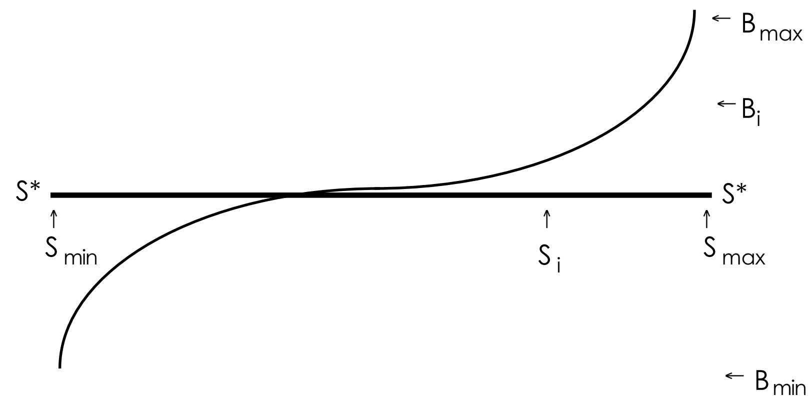
A simple depiction for behavioral adaptation at asymptote is available if it is realized that the S^*_{min} S^*_{max} gradient and the S_{min} S_{max} gradient can be superimposed in that they are by definition correlated. Behavior comes to be appropriate to the S^*_{min} S^*_{max} continuum, by coming to be appropriate to the correlated S_{min} S_{max} gradient that was created by the exposure.

Because there is a correlation at asymptote, a common *x* axis could be used to represent the behavior to both. The *y* axis could then be used to represent the behavior gradient. The following figure depicts maximum "approach" just before S^*_{max} and maximum "avoidance" at the point most negatively correlated with S^*_{max}.



$$\frac{B_i - B_{min}}{B_{max} - B_{min}} = f\,\frac{S_i - S_{min}}{S_{max} - S_{min}}$$

There is a reasonable amount of evidence that the obtained behavior shows negative acceleration as it approaches S_{max} S^*_{max}. On the other hand, there is also evidence that the function of reinforcing effectiveness is a negatively accelerated decrease function as time before the reinforcer increases (as shown in the following figure).

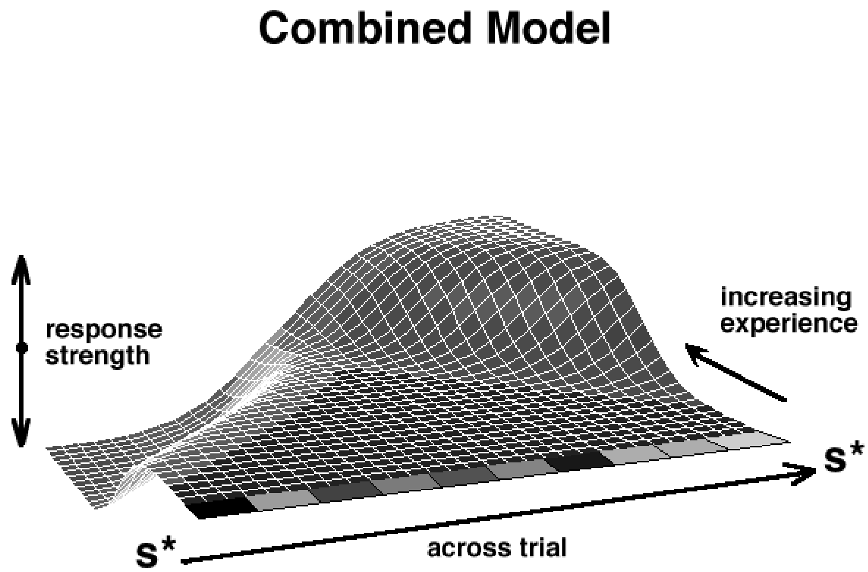


This discrepancy could be accounted for if the dependent variable were simply exhibiting a ceiling effect or if the behavior function were negatively accelerated on the S_{min} S_{max} axis and positively accelerated on the S^*_{min} S^*_{max} axis.

c. Three-Dimensional Function

A 3-dimensional depiction for the acquisition and asymptote of behavioral adaptation as a function of the S^*_{min} S^*_{max} interval is given below. As a specific example, the surface of the following figure, portrays the change in behavior as a function of both time in a fixed-interfood interval (left, right) and with increasing experience (front, back).

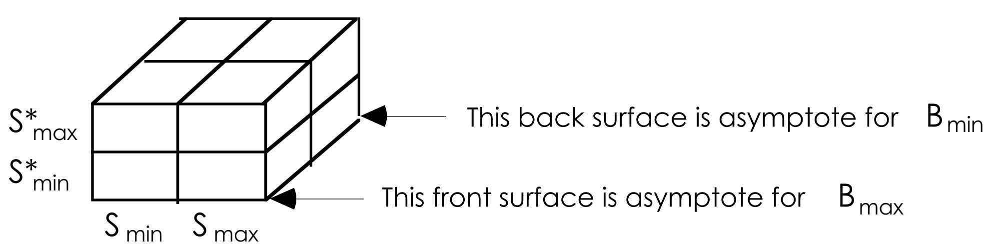
On first exposure (first left to right line across the very front of the surface), the interfood interval has no effect. With growing experience (each represented by another consecutive right to left line, each one drawn behind the other), the final and initial portion of the IFI have an increasing effect. "Approach" behavior begins to occur at the very final portion of the IFI. "Avoidance" first begins in the initial portion of the interval. Eventually after asymptotic experience (the rearmost right to left line), there is a relatively smooth transition from avoidance in the beginning of the interval to approach in the final portion of the interval; the ogival asymptote of behavioral adaptation (B_{min} to B_{max} function) seen in the two-dimensional representation is apparent across the back of the three-dimensional surface.



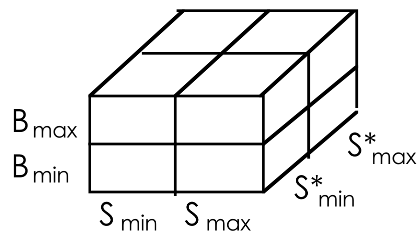
3. The Relationship of Behavioral Adaptation to its Causal Factors

a. Simple Three-Dimensional Representation

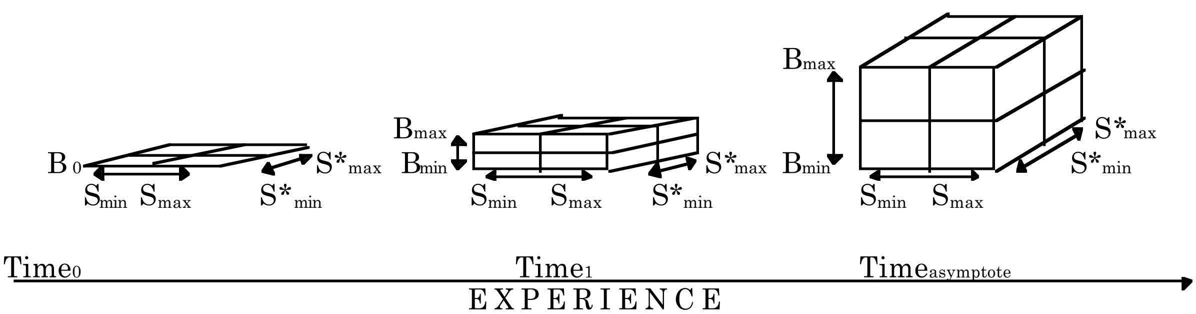
Because the correlation of antecedent stimuli and subsequent consequences produces behavioral adaptation, we need a set of axes to conveniently and simultaneously represent changes in all three variables. The following figures use three orthogonal dimensions to simultaneously display the antecedent event and subsequent outcome dimensions as well as the resulting behavioral dimension. Note that typically the experimenter establishes the S^*_{min} to S^*_{max} continuum by non-randomly presenting the reinforcer (S^*_{max}). (This necessarily produces an S^*_{min}). Often the experimenter deliberately presents a short stimulus at S^*_{max} (the CS i.e., S_{max}) and a single stimulus correlated with the entire rest of the S^*_{min} S^*_{max} gradient (the intertrial interval). The representation below appends an obtained behavior dimension to our simple contingency table.



Next we adjust the figure to put the dependent variable on the *y* axis, where we are used to seeing it, and the S_{min} S_{max} gradient on the *x* axis because we are used to having the independent variable across the *x* axis.



As seen below, the behavioral output dimension starts undifferentiated and becomes more differentiated with experience. (As was illustrated in the cylinder figure.) Using successive figures to represent increasing experience. The following three figures provide an illustration of the development of behavior (at start, at middle, and at asymptote). (It can be seen as the divergence of B_{min} and B_{max}.) Initially, behavior starts at "zero;" with experience, B_i and B_j separate more and more until they asymptotically reach B_{min} and B_{max}.

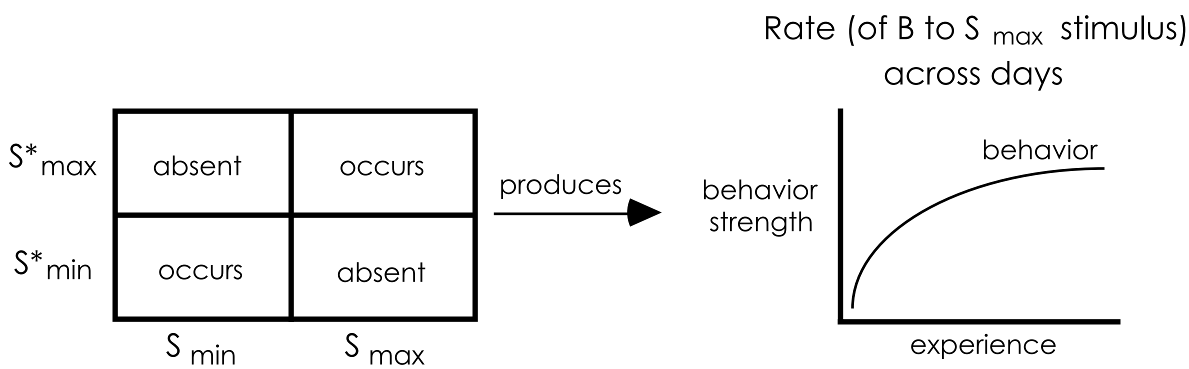


The behavioral reaction to the creation of the S_{min} S^*_{min} versus S_{max} S^*_{max} space is the creation of the B_{min} B_{max} space. A metaphor for this passive behavioral adjustment was given by the tilting log and adjusting bowling ball, and the Bezier curve examples. Yet another metaphor would be a complicated three-dimensional mobile. If you moved two weights (establish the S_{min} S^*_{min} – S_{max} S^*_{max} distance), then the reaction of the mobile would be to shift its free arm (the creation of the B_{min} B_{max} vector) such that the whole structure regains equilibrium.

b. Depiction of the Traditional View of Learning

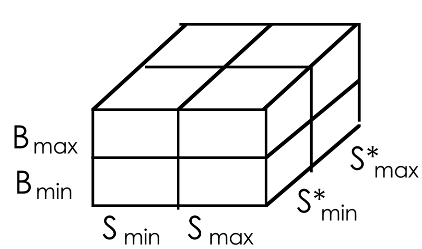
We can see how the above three-dimensional representation (or any of the previous figures for that matter) relates to the traditional learning curve in the following way: If we set up the contingency illustrated in the left portion of the figure below; then as seen over the course of experience in the right frame (i.e., the *x* axis is used to represent experience), the “strength” of B_i at S_{max} S^*_{max} changes as shown.

The right frame is the time course of the change of the back right corner of the cube (B_{max} at the S_{max} S^*_{max} conjunction) in the previous three-part figure as we progress across the three frames from the left portion of the figure to the right side (i.e., B_{max} rises). Alternatively, the right frame below is the upper diagonal line across the axis in the cylinder illustration (i.e., B_{max} rises). And finally, the right frame below details the same function seen in the rightmost edge along the *z* axis (front to back) of the three-dimensional surface figure (i.e., B_{max} rises).



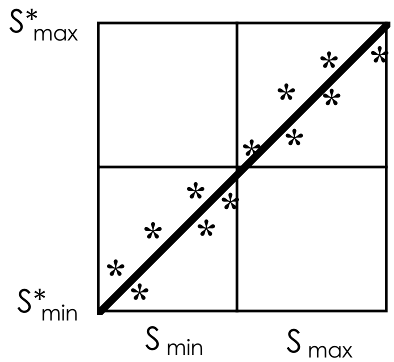
c. Depiction of the Bipolar Nature of Adaptation

However, the simple learning curve is an incomplete depiction of the behavior engendered by the S_{min} S_{max} / S^*_{min} S^*_{max} contingency. Returning to the three-dimensional representation of antecedent and subsequent events and behavior, we can map the ogival behavioral adaptation previously discussed into our three-dimensional contingency/behavior space.



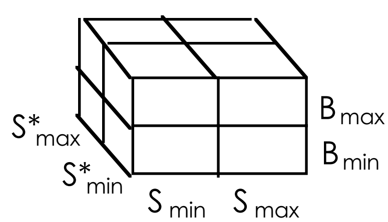
Front View

If we consider the three-dimensional cube as seen from the top, of the above figure, we would see the relationship between the stimulus and the reinforcer dimension (in a dichotomy it would be S_{min} S^*_{min} and S_{max} S^*_{max}; in a continuous model it would be the S_i's with the S^*_i's). The following figure is the same illustration of the conjunction of antecedent events with subsequent outcomes which had been used earlier. A linear regression line is again used to "typify" those conjunctions to which the subject was exposed (each specified by an asterisk). The behavior change in the organism (which results from experiencing those conjunctions) is not apparent, in that the behavior axis is represented by the dimension of the cube "coming toward and going away from the viewer" from this perspective.



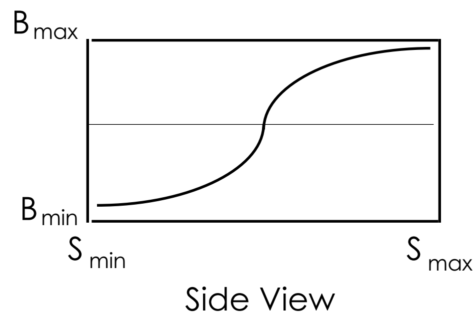
Top View

If we rotate our perspective so we looked at the cube from the side (either side would do), we would see how the vector and magnitude of behavior changes as a function of conjunctions of antecedent events with subsequent outcomes.



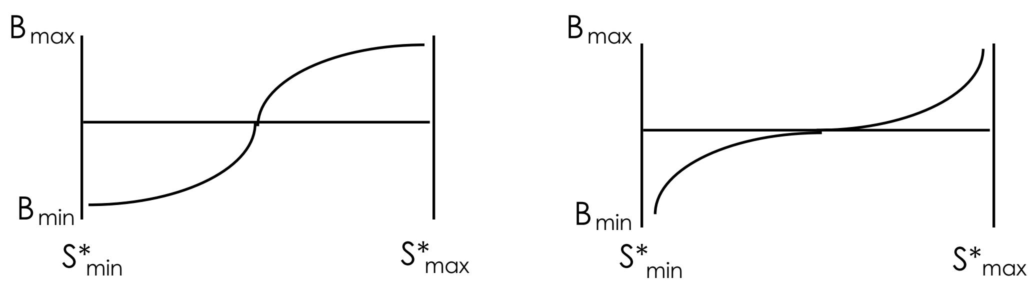
Front View

Recall that the figure which depicted behavior as a function of the S_{min} S_{max} interval was an ogive. Our cubical representation would therefore reveal the ogive below if viewed with the S_{min} S_{max} interval as the x axis and the B_{min} B_{max} interval as the y axis.



The above figure represents the behavior function extending from the lower left near corner to the upper right far corner in the preceding cube. In this two-dimensional representation of a three-dimensional figure, the scatterplot figure with the conjunctions represented by asterisks would be seen on edge perpendicular to the plane of the page (the stimulus-stimulus conjunctions have no extent in the behavior space).

Recall that, the behavior across the S^*_{min} S^*_{max} axes need not be identical to that across the S_{min} S_{max} axis. For example, the distribution across the S^*_{min} S^*_{max} continuum could be either a negatively or positively accelerated ogive, as illustrated below.



II. Special Cases of a Bipolar View of Behavioral Adaptation

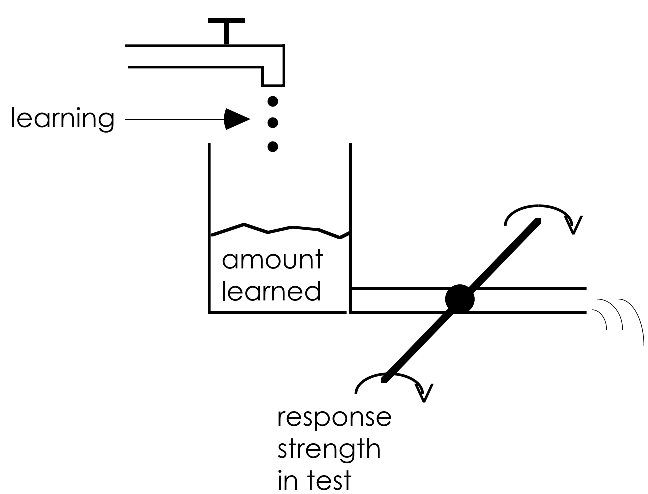
Short-term behavioral adaptation or adaptation that occurs over the minutes to days time scale is often "explained" by either a learning or a performance model.

A. "Learning Models"

Learning models of behavioral adaptation attempt to explain the incremental gain with increasing experience that is produced by exposure to a task and which results in the outcome exhibiting short-term hysteresis when the contingencies are changed. Learning models are often reductionistic. At the risk of encouraging the inappropriate reductionistic explanatory strategy, a reductionistic hydraulic metaphor could be used to quickly convey the basic predictions of learning models. It is illustrated below. Learning models typically conceptualize adaptation like the accumulation of water in a reservoir (learning) which powers a turbine (behavior) at higher speeds (more response strength) until some maximum is reached (asymptotic rate), because the reservoir can hold only so much water (asymptotic learning). The water (learning) is subsequently available to activate the turbine (behavior) at some time in the future (responding during extinction), even in the absence of further input (memory). As handy as this metaphor is, it should be remembered that it is only a metaphor. The vacuousness of the "explanation" is obvious if you imagine yourself a physics teacher explaining hydraulics and water wheels by saying they're just like animal learning. Take the metaphor for the functional properties it illustrates not as an explanation and not for how it can encourage you to think crookedly. The important predictions of this model are: 1) the output requires input, 2) the output increases with increasing input, 3) the input can be in the past, 4) more training results in more response strength and more enduring output up to some limit, and 5) at some point the enduring responding ceases in the absence of further input.

The prototypical example of a learning task would be the repetitive pairing of a bell with meat powder for some number of trials (some number of buckets of water get put into the tank). Not only will salivation (turning turbine) occur at an increasing rate up to some asymptote during training, but it will also occur to presentations of the bell during extinction for some number of trials (i.e., when called upon, the water reservoir is able to power the turbine until it runs out of water over the course of multiple tests).

"Learning" manipulations (especially when compared to "performance" manipulations, discussed below) are thought to alter the amount of learning (water) which is stored up as the result of the training procedure. From a learning theory perspective, the interesting differences in behavioral output which occur as the result of different procedures are thought to be because of differences in the amount of “learning” (“water” in the reservoir).



There are two types of reductionistic learning models. Both seek to account for why the CS is "connected" to the US and why the learning curve is negatively accelerated. US modification models argue that the US provides less and less "glue" to strengthen the connection (it is as if as the water rises, the "back pressure" slows down the faucet. CS modification models, on the other hand, argue that the glue provided by the US sticks less and less well to the CS which accounts for why the amount of connection strength diminishes with increasing experience (it's as if as the water rises more and more, less and less of the water gets into the reservoir because there are larger and larger holes in the tope of the reservoir).

1. US Modification Models

Rescorla and Wagner's Linear Operator model of learning is one of the most successful models in the history of psychology (even though it can be shown that every single aspect can be shown wrong in some sense to some degree).

a. Precipitating Findings

i. Blocking (i.e., procedure and behavior)

Kamin 1968

A	S*	A X	S*	X →
		A X	S*	X → CR
C	S*	A X	S*	X → CR
		A X	S*	X → CR

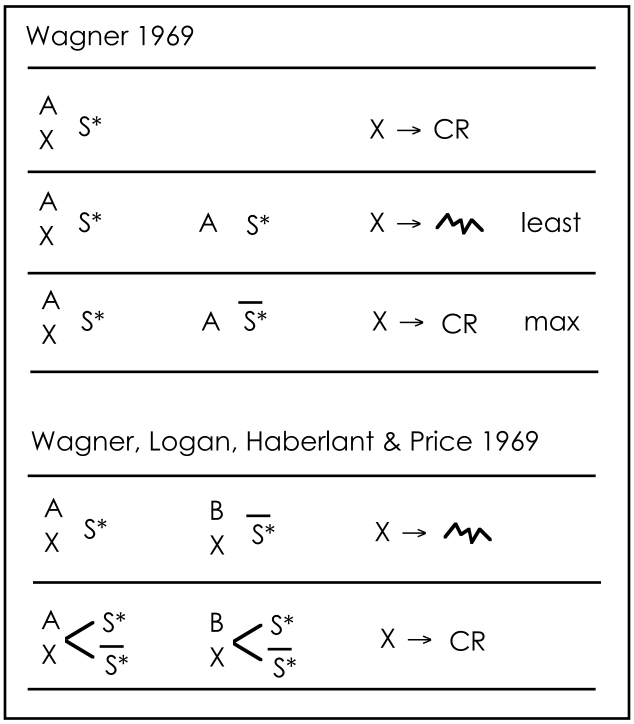
tone
light
shock
conditioned suppression

The phenomenon of blocking flies in the face of traditional notions that contiguity causes conditioning. In the above example, contiguity of *X* and S* is the same in both groups of both experiments, yet *X* controls the CR differently in the two groups.

It appears that conditioning of stimulus A interferes with or blocks the conditioning of the added stimulus *X*.

The anomalous nature of this finding is well illustrated by the reductionistic water wheel metaphor, A, X and C are reservoirs, S* is a water source, and testing A, X and C for their ability to control salivation is testing the amount of water they contain. It would seem that X should get precisely the same amount of water in all four cases, but X differs in its ability to turn the waterwheel depending on the prior history of what it's paired with. The results indicate that a preconditioned A blocks conditioning to X.

ii. "Information" Detection (i.e., procedure and behavior)



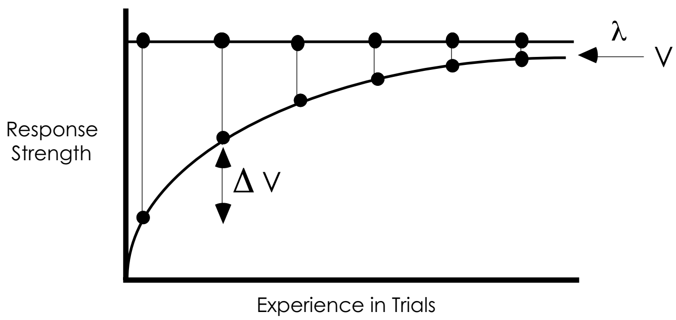
Wagner also demonstrated results which flew in the face of traditional notions of contiguity. In his case, other available contingencies modified the effectiveness of contiguity.

Wagner's identification of "information" effects went a long way toward the acceptance of "smart" animals by the research community. A behavioral approach would seek to characterize the environmental determinants of the effect, rather than giving the animal whatever skills are necessary to explain the effect.

b. The Linear Operator Model (Rescorla-Wagner)

$$\Delta V = \alpha \, \beta \, (\lambda - \Sigma \, V)$$

Δ	increment	β	US salience
V	stimulus strength	λ	limit
α	CS salience	ΣV	total all stimuli



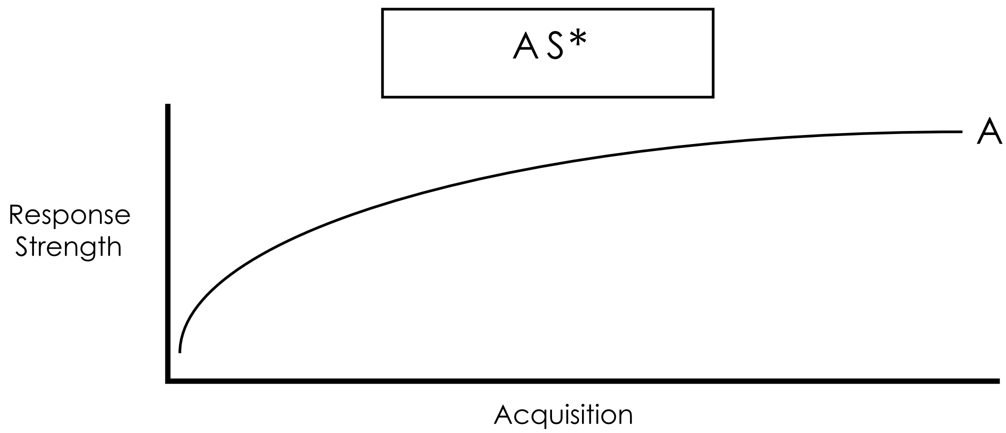
This model produces increments in response strength which are a proportion of the difference between the current response strength and the maximum possible response strength. Learning is the adjustment of behavior such that it minimizes the discrepancy between what it "is" and what it will "equilibriate at." Learning ceases when the obtained behavior matches "optimum" behavior. Behavioral control is based on all of the cues. This model does not deal with time across the trial (S^*_{min} S^*_{max} gradient), nor can it deal with sensory preconditioning. Nor does it explain the nature of the CR.

A numerical example of the Rescorla-Wagner model is illustrated below. For example, if behavior were to start at zero and λ were 100 and α*b were 0.10, then the first increment (ΔV) in response strength (metaphorical water put into the metaphorical reservoir) could be calculated.

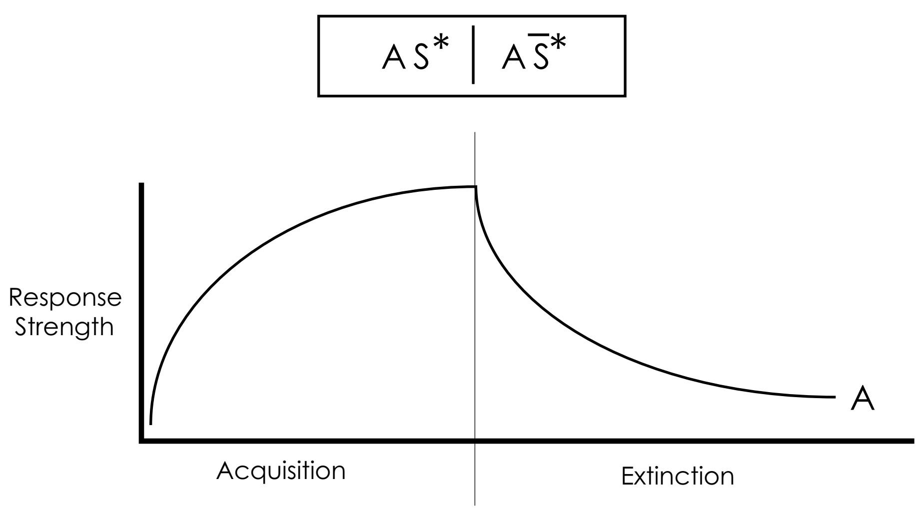
	size of increment ΔV	total response strength ∑V
ΔV = 0.10 (100–0) =	.10	.10
the second trial		
ΔV = 0.10 (100–10) =	.09	.19
the third trial		
ΔV = 0.10 (100–19) =	.08	.27
the fourth trial		
ΔV = 0.10 (100–27) =	.07	.34

The first four data points on the above figure would be at .10, .19, .27, and .34.

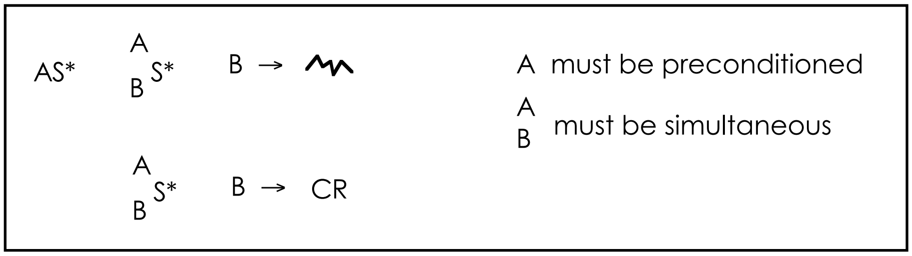
i. Explained Phenomenon: Acquisition

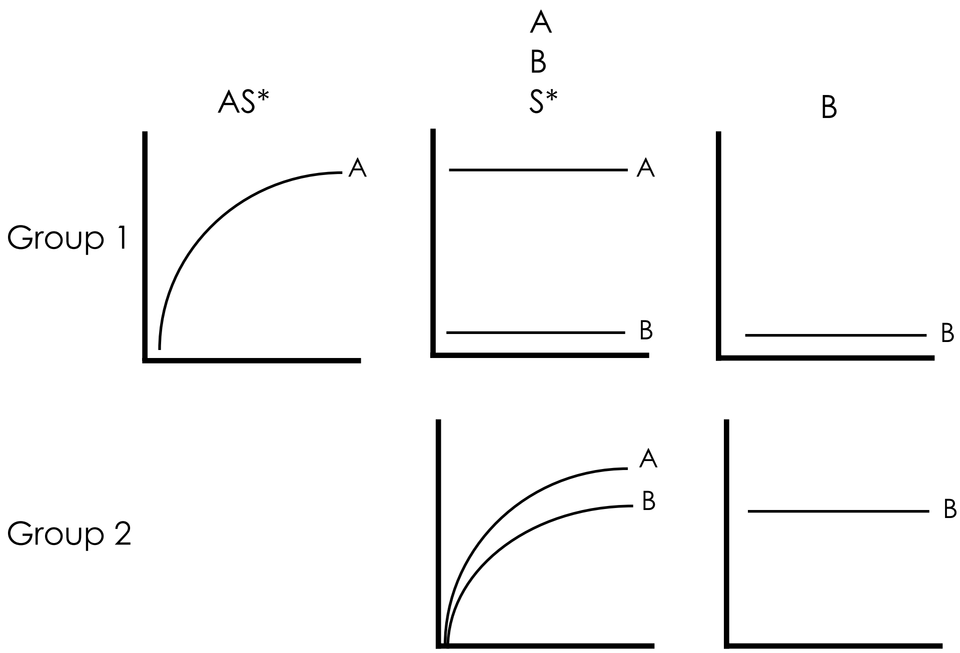


ii. Explained Phenomenon: Extinction



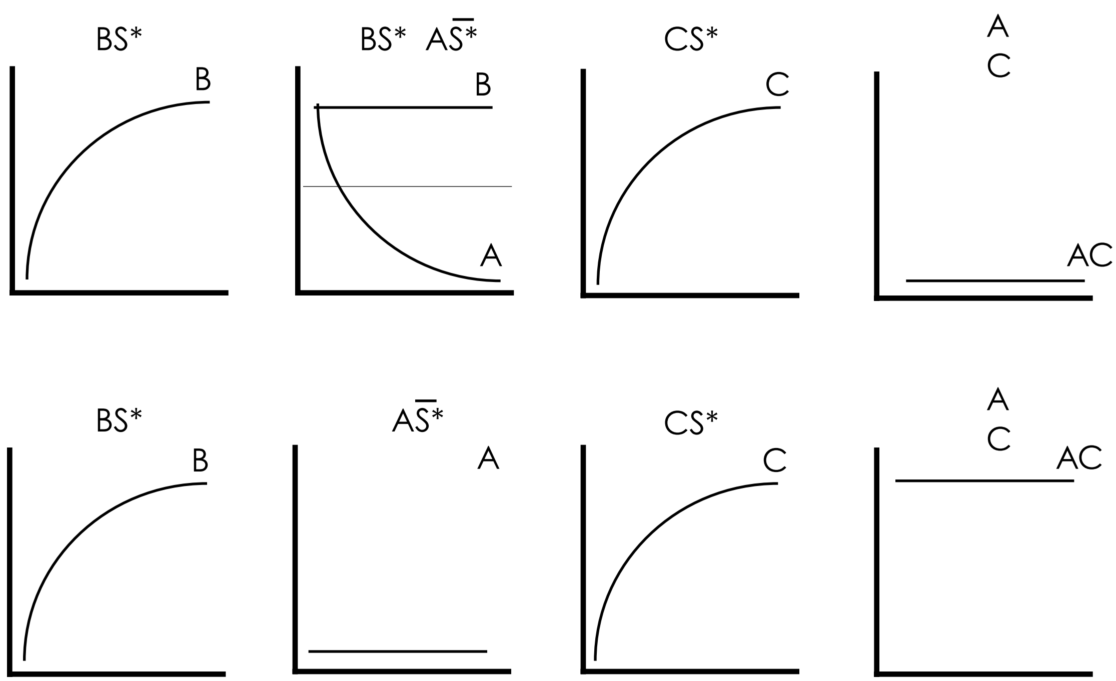
iii. Explained Phenomenon: Blocking





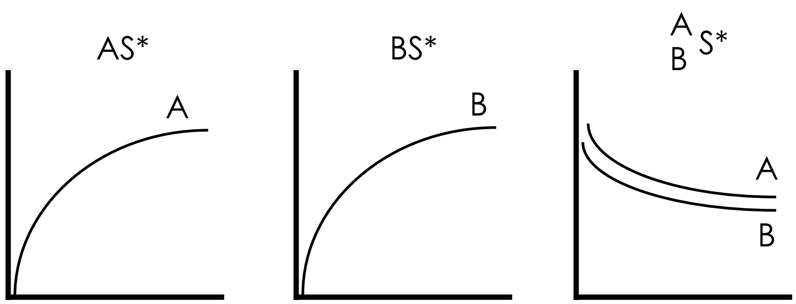
iv. Explained Phenomenon: Conditioned Inhibition

BS*	B $\bar{S}$* A	CS*	A C
AS*		CS*	A C



v. Explained Phenomenon: Overexpectation

AS*	BS*	A B S*	A → CR B → CR



c. Evaluation of the Linear Operator Model (Rescorla-Wagner)

x
x
x

Major tenets of Rescorla and Wagner's model

i. Single Associative Value

Stimulus value is the sum of excitatory and inhibitory. The stimulus cannot have both inhibitory and excitatory value. There is only one data point to plot.

But: can have stimuli that exhibit both excitatory and inhibitory properties.

ii. Path Independence

No carryover of previous experience. A value of 1/2 λ in acquisition is the same as a value of 1/2 λ in extinction. The effect of a test trial during acquisition or extinction is required to have the same effect.

But: learning and extinction and multiple learning is not the same

iii. Stimulus Competition

Total is partitioned in mutually exclusive fashion

But: what goes to one stimulus does not necessarily subtract from the other stimulus (potentiation)

iv. Exclusive US Learning

All values come from the association with a reinforcer.

But: CS to CS associations may occur for example aversion to one stimulus may be picked up by other stimuli.

v. Universal Extinction

Extinction undoes conditioning. Both excitation and extinction are indices of the same response strength.

But: conditioned inhibitors do not extinguish with simple exposure.

vi. Extinction as Unlearning

Extinction returns response strength to zero.

But: new relationships may be acquired rather than simply unraveled as if they had never occurred.

vii. Assumptions

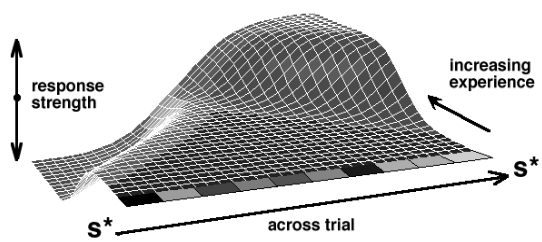
Implicitly the animal must tell stimuli apart before conditioning and must implicitly must have some window over which it averages.

But: that is what the explanation should be giving us, not vice versa

d. Linear Operator Model (Rescorla-Wagner) from a Bipolar Perspective

The Bipolar model is a more general version of the Linear Operator model.

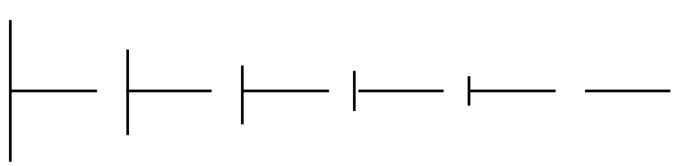
Combined Model



The Linear Operator model (Rescorla-Wagner) predicts only the general shape of the rightmost edge of the above behavior surface (B_{max} at S_{max} S^*_{max}) with each level of experience (right edge of figure). It does not specify any other aspect of the behavioral surface nor does it provide any insight into what behaviors are to be expected at various portions of the S_{min} S_{max} interval.

The Bipolar model argues that rather than considering only behavior at S_{max} as the Linear Operator model does, the entire S_{min} - S_{max} gradient must be considered. The Bipolar model iterates the Linear Operator model across the entire S_{min} S_{max} gradient, thus producing a surface rather than a line. The λ for each iteration is its respective point on the ogival function presented earlier in this chapter. That limit is set by long-term (and medium-term) contingencies.

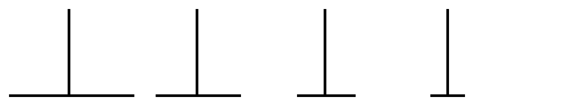
Thought: The Linear Operator model argues that the negative acceleration of learning is because [λ - $\sum V$] diminishes. An alternate conceptualization would see the negative acceleration as the result of the loss of one of the factors necessary to produce a contingency (i.e., the difference or JNDs between subsequent outcomes on the S^*_{min} S^*_{max} gradient). Essentailly, the *y* axis in the contingency scatterplot collapses to zero (no JNDs of discreancy in the outcomes).



2. CS Modification Models

There are also CS modification models of behavior change. If the CS is less and less salient then it will have a diminishing effect, thus accounting for the negatively accelerated learning curve.

Thought: Building on the collapsing axes view for US modification models, the negatively accelerated learning could be seen as due to the collapse of the x-axis (i.e., the difference or JNDs between antecedent stimuli, on the S_{min} - S_{max} gradient diminishes) thereby producing no contingency.

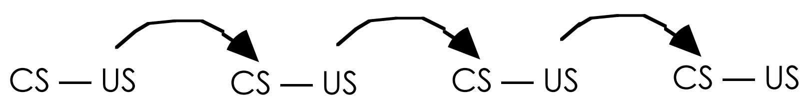


a. Precipitating Findings

x
x

b. The Pearce-Hall Explanatory Model

How surprising US was on preceding trial governs salience of CS.



US has only a prospective effect, but this approach cannot explain one trial blocking.

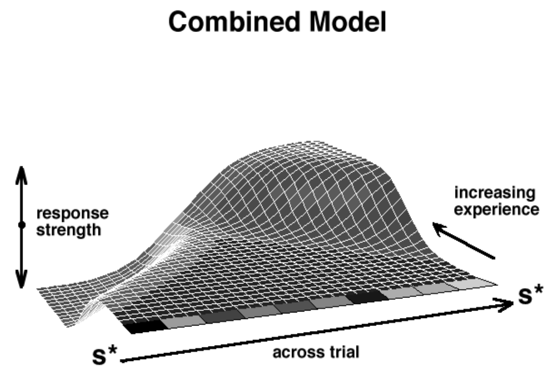
x
x

c. The Mackintosh Explanatory Model

x
x
x
x
x
x

d. CS Modification Theories from a Bipolar Perspective

The Bipolar model is a US modification model rather than a CS modification model. Basically, the bipolar model rejects the CS modification premise.



x
x
x
x
x
x

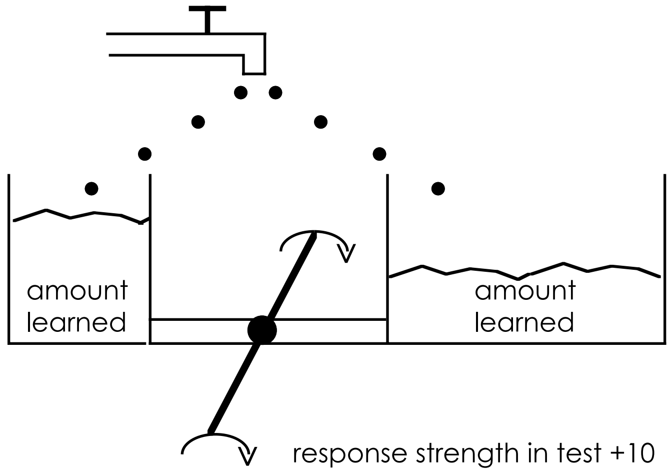
3. Other Learning Models

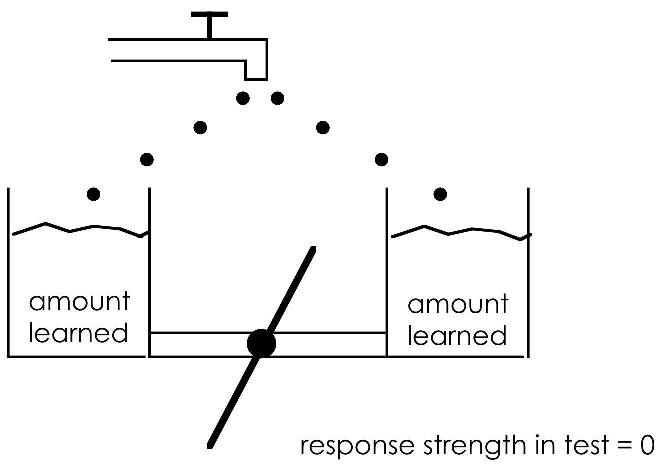
In principle, there could be other models for the learning curve based on the amount learned, or the total response strength ("volume of water" in the metaphor). other than those listed above.

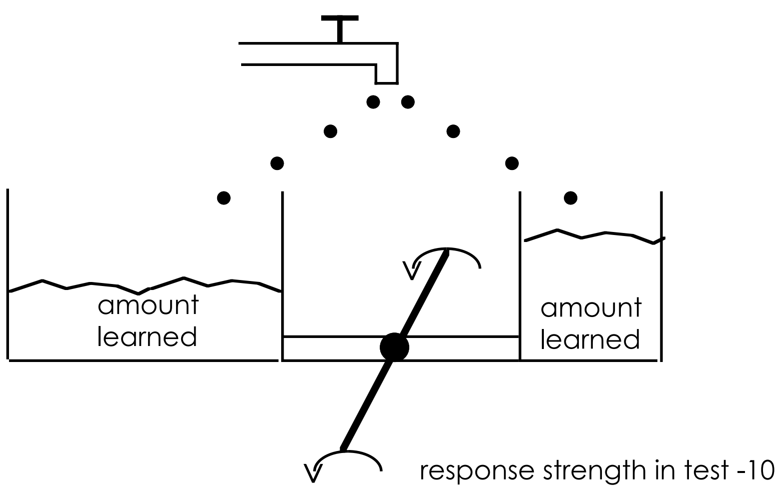
B. Performance Models

There are also models of behavior adaptation which use a different mechanism of action than that used by learning models. These "performance" models suggest that it is the relative strength of conditioning in the various contexts which determines the obtained behavior.

Returning to our reductionistic hydraulic metaphor, in this case, all stimuli receive approximately the same amount of conditioning (amount of water in the meataphor). It is the relative density of reinforcement (amount of water per reservoir width, or the relative height of the water) in the "two" stimuli which determines whether an output will occur (the turbine will spin in the metaphor) and whether the behavior will be positive or inhibitory ("direction of spin").







For example, if the duration of the CS were 10 seconds and the duration of the total trial were 100 seconds, then salivation would occur to the CS. This would mean that the probability of food in the trial was 10 times greater. (In the metaphor, this would be a fixed volume of water being placed in a 10 inch wide and in a 100 inch wide container.) If the learning situation were 10 seconds and 10 seconds(or 100 and 100), then no salivation would occur to the CS. Finally, if the durations were 100 seconds and 10 seconds, then salivation would occur in the background stimuli rather than to the CS.

The important details of the performance models are: 1) that learning occurs to all stimuli (water is in every tank), 2) that the relative "probability" of reinforcement in the stimulus determines its ability to elicit a response (width of container determines height of the water), 3) that “excitatory” learning is revealed whenever a stimulus is compared to a worse stimulus (the water pipe is connected to a lower reservoir, 4) that “inhibitory” learning is revealed whenever a stimulus is compared to a better stimulus (water pipe is connected to a higher reservoir), and finally, 5) by changing the context, excitatory, neutral, or inhibitory behavior will be revealed by any stimulus (the turbine direction is governed by the relative heights of the water in the two tanks).

1. Behavior Determined by Ratios of Delays to the Reinforcer

In this case, it is the relative delay to the reinforcer correlated with the various stimuli, that determines what behavior will occur and its vector. A short stimulus just before food presentation following a very long intertrial interval controls a high rate (i.e., in the metaphor, short stimuli are thin tanks and have a high water level the context which is the long period between food, is a very wide tank and has a very low water level).

x

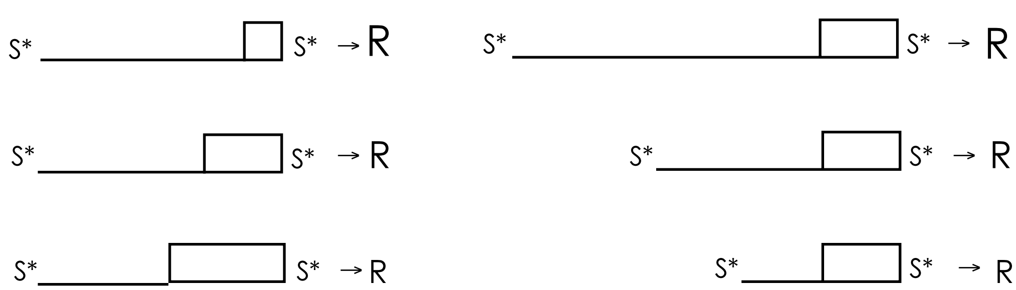
x

a. Precipitating Findings

The relative amount of responding to a CS is related to the duration of the CS with respect to the overall duration of the interfood interval.

x

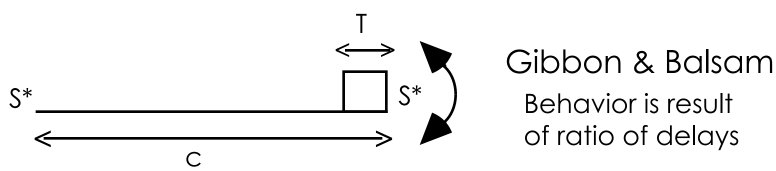
x



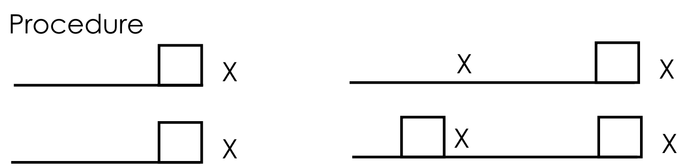
b. Scalar Expectancy Theory (Gibbon & Balsam)

Responding is controlled by the C/T ratio.

$$\frac{\frac{S^*}{T}}{\frac{S^*}{C}} = \frac{S^*}{T}\,\frac{C}{S^*} = \frac{C}{T}$$



i. Explained Phenomenon



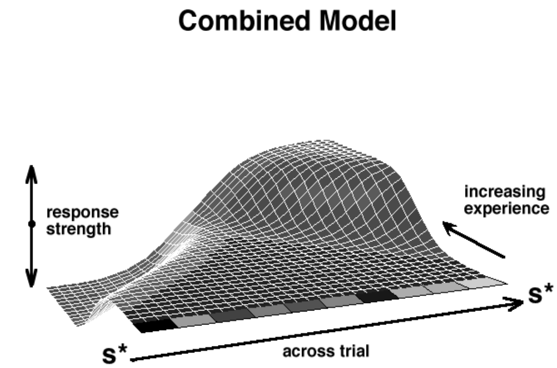
Signal extra US	
Rescorla	should be same as no extra US
Gibbon	should diminish response strength

Unsignaled extra US	
Rescorla	should diminish response strength
Gibbon	should be same as signaled, i.e., diminished response strength

c. Scalar Expectancy Theory from a Bipolar Perspective

The point of Scalar Expectancy theory is that the shorter a terminal stimulus is, relative to the food-to-food interval in a two stimulus conditioning paradigm, the sooner it elicits responding (and by implication the higher its rate) and secondly, stimuli that extend past the midpoint of the food-to-food interval into the first half of the trial fail to condition.

The Bipolar model accounts for each of these predictions in a more general continuous framework, and does not use constructs which encourage an active animal (the verbs comparison, and expectancy draw the animal as the subject of the sentence).



The bipolar model subsumes SET. As can be seen, the surface rises and goes positive (clockwise spin of turbine) soonest at its right edge. (This would be the highest possible C/T ratio.) Note also that it fails to rise at all or go positive any earlier than the midpoint of the S_{min} S_{max} gradient (C/T = 2) and finally note that the maximum rate gets higher from the midpoint on as the S_{min} S_{max} gradient approaches S_{max}. (The turbine spins faster and faster as S_{max} is approached.) Additionally, the bipolar model suggests that an analogous but opposite pattern occurs in the first half of the interval. Scalar Expectancy theory is silent on all but the final contiguous stimulus.

2. Behavior Determined by Ratios of Associative Strength

In this case, the difference in the associative strength to any two stimuli is not determined by the delay to reinforcement but rather by the relative density or probability of reinforcement between the two stimuli. It is this relative density of reinforcement that determines if behavior will occur and whether it will be excitatory or inhibitory. (From the hydraulic metaphor, it is the relative heights of the water that determines what the turbine will do).

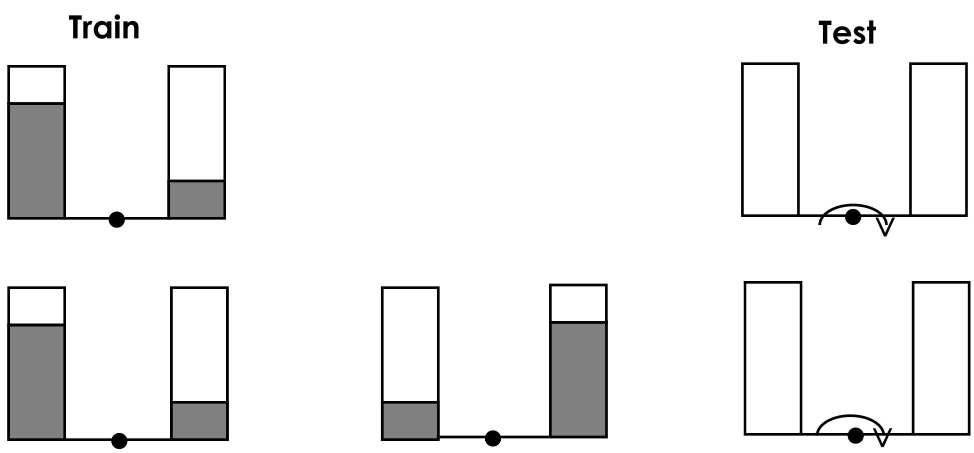
a. Precipitating Findings

x
x

b. Comparator Theory (Miller & Matzel)

Miller and Matzel have a comparator view much like Gibbon and Balsam, but in this case it is a "comparison" of associative strengths rather than a comparison of temporal delays to the reinforcer. Miller could argue that temporal comparisons are a special case of his more general associative strength comparisons. In Miller's own research, the width of the tanks (and, therefore, the relative height of the water) is determined by things such as probability of food presentation rather than delay to food presentation. Note given some form of temporal binning, temporal delay and probability are equivalent. A notable point of Miller and Mattel's theory is that the comparison is to the training conditions not the current condition.

i. Explained Findings

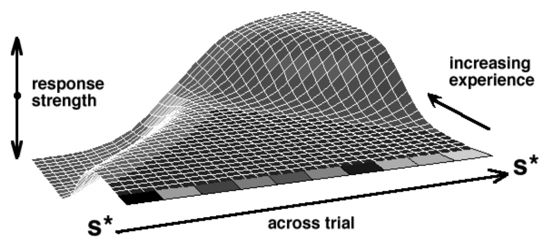


Relative associative strength in testing is to what was in training condition

c. Comparator Theory From a Bipolar Perspective

The Bipolar Model argues that the S^*_{min} S^*_{max} gradient can be stimuli along a temporal axis each one temporally nearer to the reinforcer or they can be stimuli randomly occurring in time but systematic with respect to probability of food presentation (or quality for that matter). The S^*_{min} S^*_{max} gradient creates a S^*_{min} S^*_{max} gradient when stimuli are correlated with the gradient. The behavior surface predicted by the model specifies that stimuli successively better in the "better" half of the S_{min} S_{max} continuum will control increasing rates of approach (and with less experience), while those from the midpoint to earlier in the continuum (either time or probability, etc.) will control increasing "avoidance." A notable prediction of the bipolar model is that 50% probability of food could be either S^*_{min} or S^*_{max} depending on the other food probabilities being presented in the gradient. A stimulus correlated with 50% probability of food presentation could control either approach or avoidance depending on whether it was S^*_{min} or S^*_{max} or anything in between.

Combined Model



3. Other Performance Models

a. Precipitating Findings

x
x

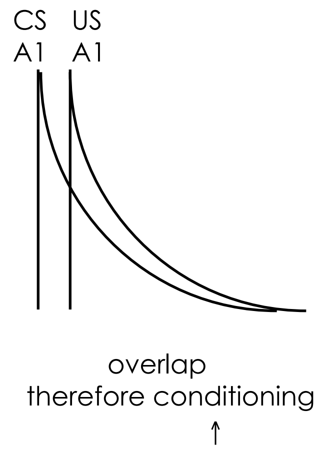
b. SOP / AESOP

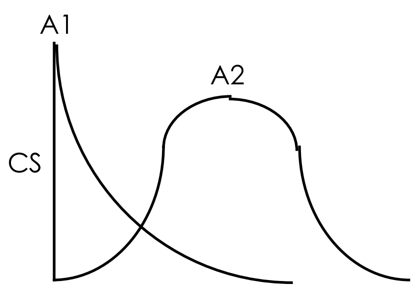
Standard Operating Procedure
Sometimes Opponent Process
Purports to Deal with both learning and performance
Real-time model

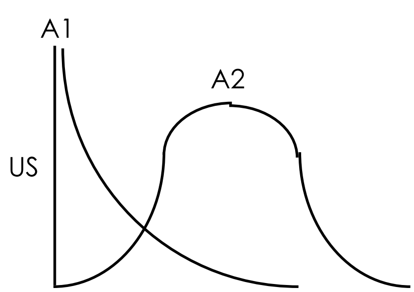
Does not appear to be very specific and appears to be unfalsifiable.

Stimulus primary A1 (Solomon & Corbett *a* process)
secondary A2 (Solomon & Corbett *b* process, but actually sometimes there is no inverse process)

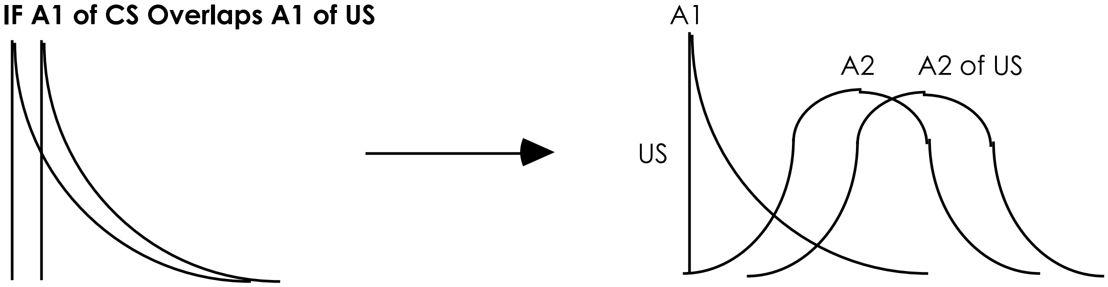
Start A1 predominates then A2 then decay







IF A1 of CS Overlaps A1 of US



AESOP Affective Extension of SOP