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A philosophy of science perspective on the quantitative analysis of behavior

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ABSTRACT

B.F. Skinner argued that the science of behavior would progress more rapidly without appealing to theories of learning. He also suggested that theories in a quite different sense were possible, but that the science of behavior as of 1950 was not ready for them. The following analysis distinguishes between Skinner's two concepts of theory. It argues that theory in the second sense has arisen in the quantitative analysis of behavior. The attempt to give a dynamic account of the static regularities of this theory, however, has produced a theory in the first sense. Within its limited domain, this theory offers a rigorous alternative to cognitive accounts of behavior. Rather than distracting attention from actual behavior, it has now led to novel predictions about it.

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1. Introduction

Skinner (1950) defines a theory as "any explanation of an observed fact which appeals to events taking place somewhere else, at some other level of observation, described in different terms, and measured, if at all, in different dimensions" (p. 193). He identifies three types of theory in the field of learning: neural, mental, and conceptual. Neural theories make neurophysiological statements or explanations when the topic is behavior and the discipline is the science of behavior. Mental theories refer to non-neural states, such as realizations or expectations. Conceptual theories make non-neural statements about "a system with a certain dynamic output" (p. 194).

He says it is not his purpose "to show that any of these theories cannot be put in good scientific order" and he concedes "it would be foolhardy to deny the achievements of theories of this sort in the history of science" (p. 194). Theories of learning may be possible, but are they necessary for a science of behavior? And if not, would the study of learning be more productive without them? These are the questions he raises.

He then proposes an approach to the study of learning that makes no use of theory in the sense just defined. This approach would take rate of responding as its basic datum. Its immediate goal would be to predict and control this datum. It would then extrapolate the results to infer probability of response in situations to which an analysis in terms of rate of response is not applicable. The justification for this approach would be "its success in an experimental science" (p. 199). He then gives examples of what this approach has already accomplished, including applications to "higher processes" such as matching to sample, discrimination, and choice. He summarizes the implications of these initial successes by suggesting that "there seems to be no *a priori* reason why a complete account is not possible without appeal to theoretical processes in other dimensional systems" (p. 215).

In his conclusion, however, he notes that theory of another sort should be possible. This type of theory would go beyond collecting uniform relationships between manipulable variables and rates of responding. Theory in this sense would provide "a formal representation of the data reduced to a minimal number of terms" (p. 216). He expresses doubt about proceeding to this type of theory soon.

We do not seem to be ready for theory in this sense. At the moment we make little effective use of empirical, let alone rational, equations. A few of the present curves could have been fairly closely fitted. But the most elementary preliminary research shows that there are many relevant variables, and until their importance has been experimentally determined, an equation that allows for them will have so many arbitrary constants that a good fit will be a matter of course and cause for very little satisfaction. (p. 216)

The following analysis distinguishes between Skinner's two concepts of theory in the study of learning. Theory in the sense that Skinner seeks to avoid will be referred to as theory$_A$. Theory in the sense that he thinks behavior analysis is capable of, but not ready

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for as of 1950, will be referred to as theory$_B$. I shall argue that a certain type of theory$_B$ has arisen in the quantitative analysis of behavior (QAB). In the attempt to give a dynamic account of the static regularities of this theory$_B$, however, a novel type of theory$_A$ has arisen within QAB. Within its domain, this theory$_A$ does a better job than theoretical$_B$ alternatives while nonetheless offering a rigorous alternative to cognitive (mental) accounts of behavior. Rather than distracting attention from actual behavior, it has now led to novel predictions about behavior.

2. Quantitative analysis of behavior

When Herrnstein (1961) published his formulation of a relationship he called "matching," behavior analysis had produced its first major empirical equation. The matching law, as originally formulated, applies to concurrent schedules that offer the experimental subject a choice between two different responses, each of which can be programmed on a different schedule of reinforcement. The schedules of greatest interest are variable-interval schedules. The matching law says that the proportion of responding on the two schedules will match the proportion of reinforcement received on them. Algebraically, this is expressed by Formula (1).

$$\frac{R_1}{R_1 + R_2} = \frac{r_1}{r_1 + r_2} \tag{1}$$

R_1 and R_2 represent total responses on the two alternatives and r_1 and r_2 represent total reinforcements on these same two alternatives. This law aggregates responses and reinforcements over an extended period of time after behavior reaches equilibrium. Herrnstein arrived at this empirical equation only after analyzing a vast amount of data and searching for an equation that fit the pattern he discerned in it.

The matching relation was held to extend to multiple alternatives, as stated in Formula (2).

$$\frac{R_1}{R_1 + R_2 + \cdots + R_n} = \frac{r_1}{r_1 + r_2 + \cdots r_n} \tag{2}$$

This was inherently interesting because it represented such a broad generalization about behavior. It meant that the number of responses devoted to a given type of concurrent behavior is a function not simply of the amount of reinforcement correlated with that behavior but also of the amount of reinforcement correlated with alternative responses. Hence, even if reinforcement for a given response remains stable, the amount of responding will decrease if reinforcement for alternative responses increases, and conversely the amount will increase if reinforcement for alternatives declines. So the amount of a given type of response is a function of how productive it is in relation to the available alternatives.

2.1. *The quantitative law of effect*

What drew even greater interest was Herrnstein's (1970) discussion of the relation between matching (which holds only when there are two or more concurrent responses) and the single-alternative case. Herrnstein noted that an experimental subject in an operant chamber always has the option of responding in ways that are not programmed by the psychologist. Even when there is only a single key programmed on a single schedule of reinforcement, a pigeon has the option of preening, flapping its wings, turning side-to-side, and so on. Let the aggregate number of these responses be summarized as R_e. Assume also that some of these responses are correlated with un-programmed reinforcement. Let the aggregate number of these reinforcements be summarized as r_e. The single-alternative chamber can now be conceptualized under the matching law as in Formula (3).

$$\frac{R_1}{R_1 + R_e} = \frac{r_1}{r_1 + r_e} \tag{3}$$

If we replace $R_1 + R_e$ with a constant, k, this formula can be rewritten as (4).

$$\frac{R_1}{k} = \frac{r_1}{r_1 + r_e} \tag{4}$$

Multiplying both sides of the equation by k then gives (5).

$$R_1 = \frac{kr_1}{r_1 + r_e} \tag{5}$$

This is known as the quantitative law of effect. It implies that the absolute amount of responding on the single programmed response is a hyperbolic function of the amount of reinforcement delivered by that response.

A corollary is that choice governs all operant behavior. Herrnstein is careful to point out that he does not mean to imply that there is an underlying process of choice, but rather to assert that what controls the aggregate amount of a specific response is the complex relationship between the reinforcement acquired by that response and the reinforcement acquired from all alternative responses. As Herrnstein (1997) notes, this is analogous to many psychophysical phenomena (p. 71). For example, the perceived brightness of a light is not a property of the absolute brightness of the light but of the relationship between its brightness and the context. A porch light that seems dim in broad daylight will seem bright at night. The contextual relationship in the case of matching is between the productivity of a specific response and the productivity of alternative responses. This is a more complex discrimination than involved in perception of brightness. One does not, however, need to know what process underlies the discrimination in order to use it in a behavioral analysis.

The analysis leading to the quantitative law of effect rests upon an assumption that the total amount of behavior of an organism is constant. The constant, k, expresses this assumption. Incorporating this assumption marks an important transition. The initial formulation of the matching law is the result of an observed empirical regularity. Herrnstein arrives at the quantitative law of effect, however, on the basis of an analytical strategy that had been successful in the physical sciences—namely, the assumption that some aspect (such as total mass or energy) of a self-contained (or "closed") system is unchanging (or "conserved"). This allows for the deduction of novel implications from previously established empirical laws. These new predictions can then be subjected to experimental test. In the case of behavior analysis, the result is the quantitative law of effect. This law is a plausible candidate for what Skinner called a rational equation. The quantitative law of effect and the matching law provide a compact set of equations that might be referred to as "matching theory$_B$."

2.2. *Herrnstein's account of the dynamics of behavior*

Matching theory$_B$ is about behavior at the point of equilibrium. The obvious question it raises is how behavior reaches this equilibrium. To answer this question, one needs an account of behavior dynamics. An early attempt to provide such an account was Herrnstein's melioration hypothesis. According to this hypothesis, "behavior shifts toward higher local rates of reinforcement" (Herrnstein, 1997; p. 75). Melioration, like matching itself, is a relation that applies to multiple responses occurring over an extended duration of time. But the duration of melioration is less than the duration of matching. It applies to local rates of responding and local rates of reinforcement. As an account of how behavior reaches