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REINFORCEMENT, FEEDBACK, AND O-RULES: AN INCONSISTENCY

REFORZAMIENTO, RETROALIMENTACIÓN Y REGLAS-O: UNA INCONSISTENCIA

FRANÇOIS TONNEAU
UNIVERSITY OF GUADALAJARA

ABSTRACT

Baum (1973) has proposed that operant behavior is the result of a feedback system comprising two distinct but interconnected functions. One, the feedback function, expresses how the environment depends on behavior. The other, the rule of the organism or O-rule, expresses how behavior depends on the environment. I argue here that irrespectively of its concentration on molar variables, the type of O-rule proposed by Baum (1973) is at odds with the concept of reinforced behavior. The inconsistency between the nature of the postulated O-rule and the concept of operant reinforcement can be seen in Baum's article itseif (1973). A revised formulation of the O-rule is proposed.

Keywords: O-rule, feedback function, reinforcement, temporal relation, elicitation

RESUMEN

Baum (1973) propuso que la conducta operante es el resultado de un sistema de retroalimentación que comprende dos funciones distintas pero interconectadas. Una de éstas, la función de retroalimentación, expresa como el ambiente depende de la conducta. La otra, la regla del organismo o regla-O, expresa como la conducta depende del ambiente. En este trabajo, argumento que independientemente de su énfasis en variables molares, el tipo de

* Correspondence concerning this article should be sent to the author at Centro de Estudios e Investigaciones en Comportamiento, Universidad de Guadalajara, 12 de Diciembre 204, Col. Chapalita, CP 45030, Guadalajara, Jalisco, México. E-mail: ftonneau@cencar.udg.mx.

regla-O que propuso Baum (1973) es inconsistente con el concepto de conducta reforzada. La inconsistencia entre la naturaleza de esta regla-O y el concepto de reforzamiento operante se ve en el artículo de Baum (1973). Se propone una formulación revisada de la regla-O.

Palabras claves: regla-O, función de retroalimentación, reforzamiento, relación temporal, elicitación

REINFORCEMENT, FEEDBACK, AND O-RULES: AN INCONSISTENCY

In his article, *The Correlation-Based Law of Effect*, Baum (1973) proposed a theoretical framework for the study of schedule-maintained performance that proved quite influential in the following years (e.g., McDowell & Wixted, 1986; Prelec, 1982; Prelec & Herrnstein, 1978; Rachlin, 1978; Staddon, 1975). Baum (1973) endorsed two fundamental notions. The first was that the analysis of behavior would best proceed at a molar level,[1] by focusing on averaged response rates, averaged reinforcer rates, and their correlations, rather than individual responses and individual reinforcing stimuli. In support of his molar view, Baum (1973) marshalled the regular relations between response and reinforcer rates that had been documented by Herrnstein (1970) and fall under the general heading of the matching law (see Davison & McCarthy, 1988).

The other crucial idea in Baum's article was to conceptualize operant performance as the result of a *feedback system*. To this end Baum (1973, p. 138) distinguished two sorts of relations present in any operant experiment, the *feedback function* and the *O-rule*. The *feedback function* (also known as rule of the environment or E-rule) expresses the way in which the environment (E) depends on behavior (B) by virtue of a reinforcement schedule (e.g., Baum, 1973, 1981, 1989). Molar feedback functions usually express reinforcer rate (E) as a function *f* of response rate (B), and amount to a mathematical description of the way in which a response-dependent schedule of stimulus presentation operates: $E = f(B)$. For example, the molar feedback function of a ratio schedule in which a reinforcer is delivered after an average of *k* responses is linear: $E = B/k$.

In and by itself, the feedback function descriptive of a reinforcement schedule implies nothing as to how organisms are going to behave on this schedule (Baum, 1989, p. 170). As Davison (1998, p. 227) put it, "feedback functions have no implication about the control of behavior by an

1. The term "molar" has multiple uses and a complex history in psychology and behavior analysis (Meazzini & Ricci, 1986). Here I will follow the usage of the term "molar" that is now standard in behavior analysis, to refer to temporal extension (molarity in *time*). See Rachlin (1986) for example.

independent variable... All that a feedback function says is that behavior will affect [an] aspect of the environment." To complete the description of the operant situation, one needs to introduce a second function, known as the rule of the organism or *O-rule* (Baum, 1973, 1989). Whereas the feedback function expresses how reinforcers depend on behavior, E = *f*(B), the O-rule expresses how behavior depends on the reinforcers, B = *g*(E). Specifying the nature of an organism's O-rule is what allows the prediction of this organism's performance, which results from the coupling of the O-rule and the feedback function.

In Figure 1 for example, which represents all possible pairs (E, B) of reinforcer and response rates, the molar feedback function (a straight line corresponding to a variable-ratio schedule) is compatible with any response rate whatsoever. But once the O-rule is specified (in Figure 1 I have assumed, for the sake of the argument, that this O-rule is a hyperbola), the only possible response rate is the rate B* that satisfies both the feedback function, E = *f*(B), and the O-rule, B = *g*(E). This rate B* appears, together with the corresponding reinforcer rate E*, at the intersection of the feedback function and the O-rule.

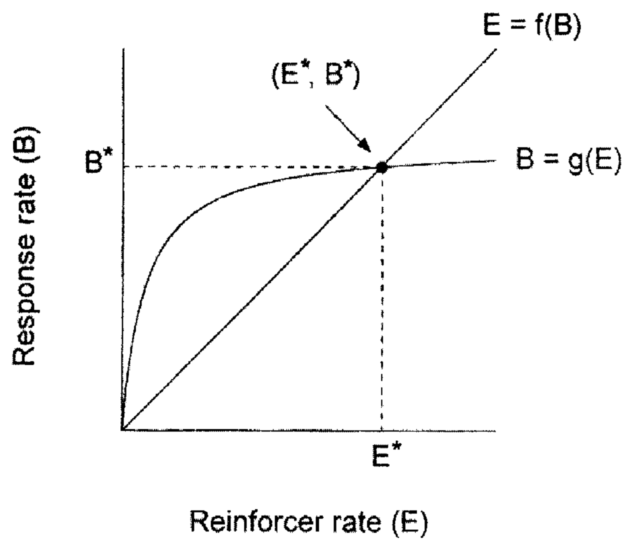

Figure 1. This panel represents all possible combinations of reinforcer (E) and response (B) rates in an operant situation. The pair of reinforcer and response rates actually observed (E and B*, respectively) must satisfy both the feedback function, E = f(B), and the O-rule, B = g(E).*

Figure 2 shows the sort of feedback system hypothesized by Baum (1973). Arrow 1 represents the feedback function, which goes from the rate of behavior (B) to the rate of a response-dependent stimulus (E). Arrow 2 illustrates the O-rule, which goes from the rate of the response-dependent stimulus to the rate of behavior.[2] In an operant experiment with rats, for example, B could consist of the rate of the animal's lever pressing and E could be the corresponding rate of food delivery. Operant reinforcement is supposed to result from the coupling of the feedback function with the O-rule (Figure 2).

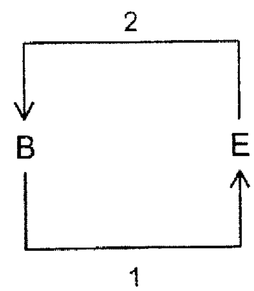

Figure 2. The feedback system for operant reinforcement is supposed to express reinforcer rate (E) as a function of response rate (B), and conversely, to express response rate (E) as a function of reinforcer rate (B). Arrow 1 represents the feedback function, and Arrow 2 the O-rule.

FEEDBACK SYSTEMS AND TEMPORAL MOLARITY

A well-known difference between Baum's and Skinner's views concerns the issue of temporal molarity. Whereas Skinner emphasized many times the role of temporal contiguity and discrete events in operant reinforcement (e.g., Ferster & Skinner, 1957; Skinner, 1948; Skinner, 1986, p. 232), Baum's molar perspective rather focussed on average response and reinforcer rates and their correlation. However, although the ideas of temporal molarity and of operant behavior as a feedback system were closely linked in Baum's article (1973), these two notions actually are independent of each other. Seeing operant behavior in terms of a feedback system does not imply relying on average rates, because feedback functions can be specified at many levels of temporal aggregation and molecular feedback functions are conceivable (see

2. No graphical representation of feedback functions and O-rules is entirely standard (e.g., compare Baum, 1973, with Staddon, 1984). The variables related by the O-rule and the feedback function can also be symbolized by different letters. Baum (1989, p. 170), for example, used B and *r* for the rates of behaviors and reinforcing stimuli, respectively, whereas I prefer to use E instead of *r* to remind the readers that the rate of a response-dependent stimulus is an environmental variable. Nothing in the present argument depends on such notational variants, however.

Berger, 1988; Davison, 1998). Conversely, one can study relations among averaged rates instead of punctate events without invoking the notion of a feedback system at all. Rescorla's (1967) formulation of the Pavlovian "contingency" as a statistical relation among stimulus rates, for example, qualifies as molar but (unsurprisingly) involves no feedback.

Thus, conceiving operant reinforcement as a feedback process is independent of the issue of temporal molarity, and may well be compatible with the Skinnerian concept of operant reinforcement if not with Skinner's own molecular assumptions about it. Baum (1973, p. 138) has indeed stated that his conception of a feedback system underlies (and therefore must be consistent with) the traditional understanding of operant performance derived from Ferster and Skinner (1957). Here is what Ferster and Skinner (1957) wrote about operant reinforcement: "When an organism acts upon the environment in which it lives, it changes that environment in ways which often affect the organism itself ... Some of these changes are called ... reinforcers: when they follow behavior in this way, they increase the likelihood that the organism will behave in the same way again" (p. 1). This quotation certainly *seems* consistent with the sort of feedback system illustrated in Figure 2, whether formulated in terms of temporally extended rates of more local properties of environment and behavior.

THE O-RULE AS AN ELICITATION RELATION

But *is* the feedback system postulated by Baum (1973, 1981, 1989) compatible with the concept of operant reinforcement? Baum's proposal comprises two parts, the feedback function and the O-rule. I will argue that Baum's description of the feedback function is correct but that his description of the O-rule isn't.

The feedback function. There is little doubt that operant procedures involve feedback functions. In operant experiments, some aspect of the environment is made dependent on some aspect of behavior, and this dependency implies the existence of a feedback function E = *f*(B). Thus, the presence of a feedback function is *necessary* for operant reinforcement to take place.[3] The presence of a feedback function in any particular situation, however, is not

3. Actually, even this point could be disputed in the light of "superstitious" reinforcement effects, in which operant reinforcement takes place in the absence of any feedback loop between behavior and its consequences. Although superstitious reinforcement probably cannot explain recurrent patterns of behavior (see Staddon, 1977; Timberlake & Lucas, 1985), its role in producing transient increases of response rate has been documented by Henton and Iversen (1978, pp. 210-213). The existence of such transient, but genuine, reinforcement effects in the absence of operant feedback loops suggests that the latter are not necessary to operant reinforcement. However, for the sake of the argument, I will waive this objection and proceed on the assumption that feedback loops are necessary to operant reinforcement. Even though necessary, they won't be *sufficient*.

sufficient for operant reinforcement. Aside from the fact that feedback can be found in physical systems that have nothing to do with operant reinforcement (e.g., Beltrami, 1998, pp. 46-48), a feedback loop B → E can be connected to a reflex (E → B) *without* bringing operant reinforcement into the picture.

Applying a stick to the nose of a donkey, for example, will make the animal move backward: the stick is an unconditional stimulus, moving an unconditional response (see Gardner & Gardner, 1998, pp. 167-168). Adding a feedback loop to this E → B reflex is easily done: apply the stick (E) whenever the donkey moves backward (B). Figure 2 is a good description of the resulting feedback system. Through the E → B reflex, the rate of moving (B) is a function of the rate of applying the stick (E), as shown by Arrow 2. And because the experimenter applies the stick whenever the donkey moves, the rate of applying the stick (E) is a function of the donkey's rate of moving (B), as shown by Arrow 1. Notice that the resulting system comprises both an O-rule (E → B) and a feedback function (B → E). The system shown in Figure 2 involves feedback, but does it involve reinforcement? I take it as obvious that the answer is no; at the very least, there is no evidence for operant reinforcement in this situation. Admittedly, the more the experimenter applies the stick, the more the donkey moves backward (E → B), and the more the donkey moves backward, the more the experimenter applies the stick to its nose. However, no operant reinforcement takes place or needs to take place. What we have here is merely an unconditional reflex (stick → moving) connected to a feedback loop (moving → stick).

The O-Rule. The previous example suggests a logical problem with Baum's (1973) formulation of the O-rule. Baum's feedback system couples a feedback function of the form $E = f(B)$ with an O-rule of the form $B = g(E)$. Although the description of the feedback function is correct, the O-rule leaves no place for, and fails to describe, reinforced behavior. What Baum's (1973) O-rule describes is unconditional respondent behavior, $B = g(E)$, and the system as a whole consists of an unconditional reflex connected to a feedback loop (see Figure 2), as in the example of the donkey.

Applied to the reinforcement of a rat's lever pressing by food (Figure 3, top panel), for example, Baum's O-rule suggests that lever pressing (B) is evoked by food or its rate E. But an adequate treatment of the notion of operant reinforcement should explain what it means for lever pressing to be *reinforced* by food—as distinguished from being *evoked* by food. No proponent of reinforcement by food believes that the alleged "reinforcement" of lever pressing by food consists merely in adding a feedback loop to a preexisting, food → pressing reflex (as in the example of the donkey).

Admittedly, some operant theorists do believe that so-called "free" operants are in fact evoked by stimuli (for further discussion see Donahoe, Palmer, & Burgos, 1997). But these theorists generally argue that the rat's pressing is evoked by the *lever* and not by the food; even from this perspective, therefore, the O-rule of Figure 2 is misplaced. Claiming that the efficacy of the lever → pressing reflex can be *reinforced* (increased) by food presentations is different from claiming that lever pressing is *elicited* by food itself or its rate, as Baum's O-rule suggests. In other theories of operant behavior, food is supposed to evoke various activities, including the activity to be reinforced (e.g., Killeen, 1994, 1998); in such theories, however, operant reinforcement is still different from mere elicitation (cf. the distinction between *activation* and *coupling* in Killeen, 1994, p. 112).

REMOVING THE LOOP

Another way of showing that the B = g(E) formulation (Arrow 2 in Figure 2) fails to capture the notion of reinforced behavior is to evaluate what happens to response rate when the feedback function is removed (Figure 3, middle panel).[4] Consider an operant situation in which lever pressing is reinforced by food, for example. In this situation, lever pressing will occur at a particular rate B* and food will be delivered at the corresponding rate E* (Figure 1). Now assume that food is presented at the same rate E*, but independently of responding (that is, *without* feedback). An O-rule of the form B = g(E) implies that lever pressing will occur at the same rate as before. The reason is that the O-rule expresses response rate (B) as a function of the rate of food (E); to be consistent with the mathematical concept of a function (e.g., Bear, 1997), a particular food rate E* must be accompanied by a *unique* rate of lever pressing B*. Any other assumption would violate the requirement that in a function (as distinguished from mere relations), the image B* = g(E*) must be unique.

But the assumption that the same rate of response B* must accompany a particular rate of food E*, whether the feedback loop is present or not, actually *contradicts* the notion of operant reinforcement. For if lever pressing in the operant situation is actually *reinforced* (as opposed to elicited) by food or its rate, then the rate of lever pressing cannot remain the same when the feedback loop is removed: rather, the rate of pressing must drop. A response rate that does not decrease or become zero, but remains constant, when the feedback loop is removed, indicates that lever pressing in the closed-loop situation was *elicited* by food, as in the example of the donkey where applying the stick led to more movement and more movement led to applying the stick.

Removing the feedback loop from an operant situation while maintaining the rate of (putative) reinforcers constant is a yoked control procedure. These procedures are employed to evaluate whether what seems to be a behavior B

4. In the middle panel of Figure 3, as in the other panels, the orientation of the arrows (left-to-right or right-to-left) is arbitrary.

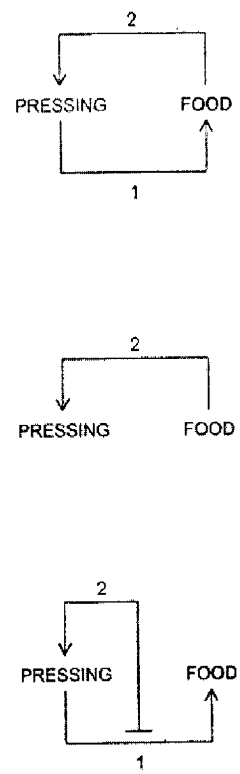

Figure 3. Top panel: Application of the feedback system hypothesized by Baum (1973) to the reinforcement of lever pressing by food. Middle panel: What happens to the feedback system of the top panel when the feedback loop is removed. Bottom panel: An alternative form of feedback system for operant reinforcement. The feedback loop is still there, but now the O-rule starts from the feedback function itself instead of the rate of food. This feedback system correctly represents behavior that is reinforced (not elicited) by food.

"reinforced" by a stimulus E (or its rate) is instead an unconditional response B elicited by E (or its rate). Interpreting yoked-control results is often difficult (Catania, 1992, p. 402), though, and some researchers have argued that even a lower rate of response B under the yoked control procedure (with the feedback loop removed) does not prove that operant reinforcement was operating in the closed-loop situation. Gardner and Gardner (1988, 1998), for example, have proposed dynamic elicitation model which may explain differences of response rate between operant (closed-loop) and yoked (open-loop) procedures *without* assuming any process of operant reinforcement.

Thus, a difference of response rate between operant and yoked situations may not prove that the relevant response is sensitive to operant reinforcement. One thing is clear, however: if response rate B* does *not* differ between operant situations and yoked situations with the same stimulus rate E*, then there is no reason to assume that operant reinforcement operates in the closed-loop situation. On the contrary, the data suggest that the allegedly reinforced response is *elicited*, and not reinforced, by E*. Far from being consistent with the concept of operant reinforcement, an O-rule of the form B = *g*(E) describes an unconditional reflex insensitive to operant reinforcement. Whether the O-rule characteristic of elicitation is connected or not to a feedback function (as in Figure 3, top and middle panels) changes nothing to the nature of the former.

This logical flaw in Baum's (1973, 1989) approach to O-rules has perhaps been obscured by the mathematical proposals of Prelec (1982) and Rachlin (1978), in which a generic feedback function is used to model a range of operant and respondent procedures. Varying the parameters of the generic feedback function allows one to pass continuously from variable-ratio to variable-interval to variable-time schedules of food delivery, for example. These elegant proposals raise no problems so long as they are seen as what they are: descriptions of different *procedures* at a molar level. But the indisputable difference between the flat feedback function of Pavlovian *procedures* (including yoked procedures) and the non-flat feedback functions of operant *procedures* has no clear implications for the nature of behavior in the latter case, since, as we have seen, the mere presence of a feedback loop E = *f*(B) in an experimental situation does not guarantee that the resulting behavior is operant behavior (see Higgins & Morris, 1985).

THE SOURCE OF FEEDBACK IN OPERANT BEHAVIOR

Baum's (1973) proposed feedback system, with its O-rule which expresses behavioral variables (B) as a function of stimulus variables (E), is inconsistent with the concept of operant reinforcement. The feedback system shown in the lower panel of Figure 3, however, is consistent with the concept of reinforcement and does distinguish behavior reinforced by food from behavior elicited by food. This system includes the usual feedback function (Arrow 1), but adds an O-rule (Arrow 2) that starts from the *feedback function itself* instead of the environment. In this modified arrangement operant behavior is a function, not of the environment *per se* (as would be fitting for behavior elicited by food), but of its own *relation* to the environment (the feedback function). A feedback system with this type of O-rule correctly predicts what the results of a yoked-control procedure should be if behavior in the closed-loop situation is actually reinforced by food: because B is supposed to depend on the feedback loop, as opposed to the mere stimulus rate E, response rate should drop when the feedback loop is removed while keeping E constant.

The difference between the top and lower panels of Figure 3 is easily overlooked when portraying operant behavior as a "function of its consequences." However trivially, any unconditional respondent behavior connected to a feedback loop will be a "function of its consequences" (as in the top panel of Figure 3 and the example of the donkey), whereas only operant behavior is a function of its relation to its consequences. Hull, Langman, and Glenn (2001) thus put it well when they write that "some *relations* between behavior and consequent stimulation have the effect of increasing the frequency of responses" (p. 523, emphasis mine). In operant reinforcement, what increases response rate is some temporal relation between behavior and its consequences (as in the bottom panel of Figure 3), not these consequences *themselves* (as the top panel of Figure 3 incorrectly suggests).

Both interpretations of reinforcement (the correct as well as the incorrect one) can be found in Baum's (1973) article on O-rules and feedback. After suggesting, incorrectly, that reinforcement involves a feedback system with an O-rule of the form B = g(E), in his account of delayed-reinforcement phenomena Baum (1973) actually discusses a feedback system of the sort shown in the bottom panel of Figure 3. To explain the detrimental effect of imposing a delay between the operant response and the reinforcer, Baum (1973, p. 141) proposes that such a delay loosens the global correlation between response and reinforcer rates, which is equivalent to adding noise around the feedback function. Irrespectively of its empirical adequacy (Ettinger, Reid, & Staddon, 1987), this account assumes that reinforced behavior is a function not of the environment (Figure 3, top panel) but of a particular set of relations between behavior and the environment (Figure 3, bottom panel). For whatever the slope of a feedback function is, clearly it is not an environmental parameter but a temporal relation or correlation between environment and behavior. Whereas Skinner (1938) would have described the E-rule feeding into the O-rule (see Figure 3, bottom panel) in terms of contiguity among discrete events, Baum (1973) describes it as a correlation between two molar rates (E and B). Independently of the molar emphasis, however, we are back to the understanding of reinforced operant behavior as being governed, not by the environment itself (Figure 3, top panel), but by its own relation to the environment (Figure 3, bottom panel).

CONCLUSION

When dealing with open- and closed-loop situations, at least three cases should be distinguished: behavior elicited by food in the absence of a feedback loop (Figure 3, middle panel), behavior elicited by food in the presence of a feedback loop (top panel), and behavior reinforced by food (bottom panel). The existence of a feedback loop in an experimental situation is compatible with the latter two outcomes. The putative operant response could be merely elicited by food, in which case the situation involves a reflex connected to a feedback loop; or responding could actually be sensitive to the feedback loop, in which case the situation involves operant reinforcement.

Importantly, the conceptual distinction illustrated in Figure 3 tells us nothing about the empirical adequacy of operant reinforcement concepts. That the bottom panel of Figure 3 correctly represents operant, reinforced behavior does not prove the existence of the latter. Perhaps Baum's framework (1973), with its source of feedback in the environment itself as opposed to the relation between behavior and the environment, is right after all. Perhaps what we think of as "operant behavior" is nothing more than elicited behavior with an added feedback loop, as Gardner and Gardner (1988, 1998) have argued and as the top panel of Figure 3 suggests.

Irrespectively of the empirical evidence, however, the conceptual point remains: A feedback system with an O-rule of the type proposed by Baum (1973, 1981), that seems to embody our common understanding of reinforced behavior, is actually at odds with it. This conceptual point should be clear before turning to the empirical evidence for or against the existence of reinforcement as a process distinct from elicitation.

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