RESPONSE DEPRIVATION:
AN EMPIRICAL APPROACH TO INSTRUMENTAL PERFORMANCE

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The empirical law of effect is criticized as an incomplete step in the development of empirical laws of instrumental performance. An alternate approach to the prediction of performance is developed which follows Premack in relating instrumental performance to empirical measures of operant behavior. However, it is concluded that instrumental performance is not determined by a probability differential in operant baseline between the instrumental and contingent responses, but by the condition of response deprivation. This condition depends on the terms of the schedule as well as operant baseline measures. The response deprivation condition occurs in a contingency if, in performing the instrumental response at operant baseline, the subject would perform less than his operant baseline of the contingent response. Instrumental performance appears directly related to the amount of response deprivation. Response selection and the application of the response deprivation approach are discussed.

Learning theorists of the most disparate persuasions agree that the consequence of an instrumental response is an important determinant of the subsequent probability of that response. While it is generally acknowledged that some consequences increase the probability of an instrumental response, and others do not, there is not much agreement on what property of the consequence produces the increase. Failure to resolve this theoretical issue, combined with the success of Skinner's (1938, 1950) atheoretical approach, produced a pragmatic approach to instrumental learning. The empirical law of effect ignored conflicting theoretical views and simply asserted that some consequences have a response-increasing property, and other consequences do not. Spence (1956) expressed the law:

Responses accompanied or followed by certain kinds of events (namely, reinforcers) are more likely to occur on subsequent occasions, whereas responses followed by certain other kinds of events (namely, non-reinforcers) do not subsequently show a greater likelihood of occurrence [p. 33].

We will contend that in spite of its longevity, the empirical law of effect is an inadequate empirical guide to the prediction of instrumental performance. It is useful only under a restricted set of conditions, and is based on a questionable model of instrumental learning. We will suggest an alternative approach to instrumental performance which has a more adequate empirical base.

INADEQUACY OF THE EMPIRICAL LAW OF EFFECT

The inadequacy of the empirical law of effect as a predictor of instrumental performance was first pointed out in a criticism that the law is circular (Postman, 1947). The probability of the instrumental response is the only independently defined variable in the empirical law of effect. The other variable, the reinforcer, is defined by the effect it is assumed to have on the probability of the instrumental response. If a particular consequence is associated with an increase in the probability of the instrumental response, then it is a reinforcer; otherwise, it is not. Employed in this fashion, the empirical law of effect only defines a reinforcer; it is not a law.
In a classic defense, Meehl (1950) suggested that the empirical law of effect escaped the problem of circularity if reinforcers were treated as transitiutional in their effects. A reinforcer identified in one situation can be predicted to increase the probability of an instrumental response in other situations. Meehl's solution provides the empirical law of effect with empirical content (Hilgard & Bower, 1966) but is objectionable on at least two grounds. First, though probably intended only as an interim solution, the concept of transitiutionality appears to have hindered the development of more adequate laws of instrumental performance. Researchers have limited their efforts to cataloging events which increase instrumental responding (Miller, 1963). Such a catalog is a first step in the development of scientific laws, but the next step, discovering the attributes of the events which determine their effect, is overdue in the case of the empirical law of effect.

Second, the transitiutional hypothesis of reinforcers is successful in predicting commonly investigated phenomena, such as bar pressing for food by hungry animals. However, this predictive success appears more related to a fortuitous, situational consistency than to an analysis of the basic laws involved. An analogy will clarify this distinction.

A well-known physical law states that the pressure of a gas in a fixed space is a direct function of its temperature. Suppose, however, that the concept of temperature were not known but that researchers had cataloged “pressurizing agents” which increased the pressure of gas systems to which they were added. If all gas systems considered had similar initial temperatures, then all pressurizing agents would be transitiutional in their effects. However, if the gas systems differed in initial temperature, then a given pressurizing agent might increase, decrease, or have no effect on the pressure of a system to which it was added. Such phenomena can be understood and predicted only by developing the concept of temperature and the associated gas laws.

If the problem of identifying reinforcing agents is at all analogous to the problem of identifying pressurizing agents, then there should be many exceptions to the transitiutional property of reinforcers. Reinforcers should increase, decrease, or have no effect on responses which they follow. In fact, there are widely known exceptions to the transitiutional property. For one, a food consequence will not typically increase instrumental responding in a satiated rat. This result is so intuitively obvious that little has been made of it. Instead of modifying their approach to deal directly with this exception, researchers have treated hunger as a boundary condition for the application of the empirical law of effect. One defense of this boundary condition is that the animal must eat the food in order for an effect to occur. Since a satiated rat does not eat food, no reinforcement will occur.

However, this escape clause does not apply to a series of studies reported by Premack (1965). Premack combined two known reinforcing responses in the same schedule, one as the instrumental response, and the other as the contingent response. One such schedule involved manipulation responses in monkeys (Premack, 1959, 1963b), and another, wheel running and licking in rats (Premack, 1962, 1965). In each schedule both responses had a nonzero operant level, and each closely followed the other. The empirical law of effect therefore appears to predict that each should reinforce the other. The results showed that, at most, only one response in a given contingency increased in probability.

**Probability-Differential Hypothesis**

Premack (1959) was able to predict which response would increase by comparing the relative probabilities of the two responses in a paired operant baseline. He formalized his discovery in the probability-differential hypothesis: "For any pair of responses, the more probable one will reinforce the less probable one [p. 132]." Response probability is determined from the duration of the instrumental and contingent responses in a paired operant baseline. Dу-
ration of responding is used rather than rate on the grounds that the clock does not move faster or slower as a function of the particular response involved. The paired baseline session is identical to the contingency session in terms of all stimulus, organismic, and procedural conditions, except that access to both responses is free rather than regulated by a schedule.

The probability-differential hypothesis provides a testable alternative to the empirical law of effect and surpasses it in ability to predict instrumental performance before the fact. The probability-differential hypothesis is potentially applicable to any response without prior experience in using it as a reinforcer. Further, this hypothesis predicts the outcome of contingencies between two known reinforcers and accounts for the failure of a food consequence to increase bar pressing in a satiated rat. Eating is not a high-probability response in a satiated rat.

Despite its advantages, the probability-differential hypothesis has generated a relatively small number of studies and has only slowly entered the mainstream of reinforcement theory (Kling & Schrier, 1971). Most textbooks of learning continue to feature the empirical law of effect as the preferred technique for predicting instrumental performance (Deese & Hulse, 1967; Hall, 1966; Hilgard & Bower, 1966).

The reasons for this are complex. The probability-differential hypothesis has been criticized for making mistaken predictions, though some of these claims appear to be based on misunderstanding rather than experimental disproofs. Other problems in-

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One of the most frequently cited criticisms of the probability-differential approach was raised by Miller (1963). He pointed out that a high probability of wheel running could be obtained by shocking a rat in a running wheel, but he doubted that the animal would therefore perform an instrumental response to turn on the shock and run. Miller's thought experiment violates a basic procedure of the probability-differential approach. The contingency should change only the rules for access to the contingent response. Any other part of the stimulus situation or the organismic variables eliciting approach to the contingent response should remain constant. Miller's suggested procedure is analogous to measuring eating when a rat is food deprived but imposing a schedule when the rat is satiated. To complete the analogy, if the rat performed the instrumental response, it would be simultaneously deprived and given food. It is possible that such a schedule might produce an effect, but to predict its outcome from the probability-differential approach would require a different baseline than the type Miller suggested. A schedule appropriate to Miller's baseline would make wheel running contingent upon an instrumental response in the presence of constant shock. Under these circumstances, it seems probable that the rat would learn to release the wheel to run.
following the to-be-strengthened response. The frequency and contiguity with which a reinforcer follows a response determine the final strength of that response.

The empirical law of effect and the reinforcement model share a common heritage, Thorndike's law of effect. As a result, they are virtually identical in their assumptions. Some versions of the empirical law of effect contain no reference to learning or strengthening; however, many do (e.g., Skinner, 1938, 1971), and there seems little doubt that strengthening is generally assumed to be the basis for an increase in instrumental responding (Herrnstein, 1970). To displace the empirical law of effect, it will be necessary to displace the reinforcement model and its strengthening process as well.

Despite its plausibility and widespread acceptance, the appeal of the strengthening process is primarily intuitive; the process itself is a mystery. The work of Lashley (1950) and more recent researchers (John, 1967, 1968) reveals no simple analog of strengthening in the brain. Further, since its antecedents can be determined only by example, the conditions for strengthening can be inferred only after the fact of instrumental performance is established.

The reinforcement model does provide a unitary basis for response selection, storage of information, and performance in its strengthening process; but the advisability of such a simplification is questionable. Low intercorrelations between different measures of performance (Kimble, 1961), the phenomena of latent learning (Blodgett, 1929; Kimble, 1961) and all-or-none learning (Restle, 1965), the effects on performance of incentive shifts, intermittent reinforcement, and overlearning (Hall, 1966; Walker, 1964, 1969), all suggest the existence of multiple processes in instrumental learning. More recently, Estes (1969, 1971), Atkinson and Wickens (1971), and Longstreth (1972) argued for multiple processes by claiming that a reinforcer may affect learning by virtue of its contiguity with the instrumental response but that it has no direct effect upon performance. Perkins (1968), too, suggested that different variables and laws determine acquisition and asymptote of instrumental responding.

Far from discrediting the reinforcement model, these problems have set the stage for its elaboration. Concepts such as \( r_{a-s_g} \) (the fractional anticipatory goal response), \( r_{r-s_f} \) (the fractional anticipatory frustrative response), and attentional processes have been added to the model, largely without an increase in its empirical ties. The reinforcement model has become a paradigm in Kuhn's (1964) sense of the term—a model which directs experimentation and interpretation but cannot itself be tested. It can only be displaced by an alternative model.

In addition to those above, there are two further arguments for displacing the reinforcement model, arguments which we feel suggest the direction a new model should take. First, the reinforcement model fails to set any a priori limit on asymptotic performance. Such a limit would seem to be a prerequisite for a model of performance. The absence of such limits in the reinforcement model points up its focus on the hypothetical learning-reinforcement process instead of on performance.

The second criticism disputes the assumption of the reinforcement model that a contingency affects performance only by providing contiguity between the instrumental response and a reinforcer. Premack (1965) reasoned that if this assumption were true, then any condition in which a high-probability response quickly and repeatedly followed a low-probability response should produce an increase in the low-probability response. As a test of this assumption, Premack examined paired-baseline sessions of licking and wheel running in rats in which licking was the higher probability response. He defined as a contiguous pairing any occasion on which licking followed wheel running.

The concepts of \( r_{a-s_g} \) and \( r_{r-s_f} \) are related to the empirical phenomena of anticipatory consummatory responses and anticipatory emotional responses, respectively. However, independent measures of these phenomena have not correlated particularly well with the course of instrumental learning. In practice, \( r_{a-s_g} \) and, to a lesser degree, \( r_{r-s_f} \) are used without reference to an empirical base other than their assumed effects on learning and performance.
ning within two seconds. On the average these pairings occurred more than 18 times in a 15-minute session, but no increase in wheel running occurred.

In searching his data for other possible functions of a contingency, Premack observed that schedules which produced instrumental performance also reduced the contingent response below its paired baseline. To test the importance of this reduction, Premack set up a schedule between wheel running and licking which required only a small amount of the less-probable running response for access to a large amount of the more-probable licking response. This schedule did not reduce the contingent response: By running at baseline level, the animal was able to gain access to its baseline level of licking. Premack reasoned that if reduction of the contingent response is necessary for instrumental performance, then no increase in running would occur, despite the fact that the contingent licking response had a higher operant probability than running.

This schedule produced no increase in running, nor did running decrease when the opportunity to lick was withdrawn in an extinction test (Premack, 1965). The only difference between this schedule and previous schedules which did produce instrumental running (e.g., Premack, 1962) was that previous schedules reduced the contingent response below its baseline, and this schedule did not.

Premack (1965) concludes:

Apparently an invariant though unrecognized component of a contingency is a decrement in the amount of responding that occurs to the contingent stimulus, relative to what would occur were the stimulus free. Our results suggest that this reduction is vital, that reinforcement cannot be initiated without it. We are thus led to suppose that although the reduction is not a necessary feature of the contingency, it nonetheless occurs as a routine part of the reinforcement procedure. It would be preferable to elevate this factor from its obscure status as a hidden concomitant to that of a public operation where its consequences for theory can be examined (pp. 172-173).

In the next section we will present an alternative to the reinforcement model. This alternative suggests the development of empirical laws more adequate than the empirical law of effect. Both the model and the suggested laws are directed at the prediction of asymptotic performance under a schedule. In so far as is possible, our intention is to isolate the determinants of instrumental performance from those of response selection and acquisition. We assume that the subject is able to learn what-leads-to-what in a given schedule. Our primary interest is the initial formulation of empirical laws of asymptotic instrumental performance.

TOWARD AN ADAPTIVE MODEL OF PERFORMANCE

Two major assumptions underlie the adaptive model. The first is that instrumental performance is a result of conflict between the freely occurring behavior of the animal and the restrictions of a schedule. The effects of a schedule cannot be understood or predicted by considering the contingency situation alone. A consequence is not merely the presentation of an isolated stimulus event but is better viewed as access to a response (the contingent response), which, along with the instrumental response, shows characteristic levels and patterns of performance in a free behavior baseline. A schedule imposes sequential and quantitative constraints which typically conflict with the patterns of free behavior. Asymptotic instrumental performance represents a resolution of this conflict.

The most common conflict produced by a schedule is a restriction of access to the contingent response. One way of imposing this restriction is to require the animal to perform a relatively large amount of the instrumental response in order to gain access to a relatively small amount of the contingent response. An increase in instrumental responding reduces the conflict between the contingency schedule and the free-responding baseline by increasing access to the contingent response.

Though the adaptive model in this general form does not predict the amount of increase in the instrumental response, it does suggest a limit to this increase. In general, the
subject should not perform more of the instrumental response than is necessary to return the contingent response to its baseline. To exceed the baseline of the contingent response would necessitate increasing rather than decreasing the degree of conflict between baseline response levels and those in the contingency session.

For example, if a hungry rat is given free access to food and a bar in a baseline session, it will spend considerably more time eating than bar pressing. In a typical contingency, the schedule demands that the rat perform a large proportion of its baseline amount of bar pressing for access to a small proportion of its baseline amount of eating. By the time the rat has bar pressed its baseline amount, it will have gained access to only a small fraction of its baseline amount of eating. Additional bar pressing produces more food, thereby allowing the animal to approach its baseline amount of eating. From the point of view of reducing conflict, the rat should press the bar more than its baseline but not more than the amount necessary to reproduce its baseline amount of eating.

The second major assumption of the adaptive model is that resolution of the conflict between the determinants of free behavior and the requirements of the schedule is based on the biological equipment and capacities of the animal involved. An adaptive outcome is not necessarily most efficient (profitable) in obtaining access to the contingent response (Herrnstein, 1970). In the example above, the rat may perform responses other than bar pressing in reaction to the scheduled restriction of food. It might escape its cage, eat sawdust, nibble its pellets more efficiently, alter its metabolism of fats, bite the experimenter, or gnaw the bar. These outcomes are not equally profitable, but all are adaptive in that they follow from the organism’s functioning as a biologically evolved system and in response to the imposition of the schedule.

Animals would be expected to show efficient performance only if their phylogenetic and ontogenetic programming provided the possibility of such a solution to the conflict imposed by the schedule. The fact that much behavior under a schedule appears to take the form of efficient instrumental responding is probably due primarily to a judicious selection of apparatus, animal, and procedure, and only secondarily to the general effect of a reinforcer.

In our development of an empirical approach to performance under a contingency, we will restrict ourselves to the prediction of asymptotic instrumental performance in single response, instrumental schedules. Multiple schedules will not be considered. Instrumental performance is defined as an increase in the amount of the instrumental response over its paired baseline. An instrumental schedule is one in which the amount of contingent response earned is uniquely and directly related to the amount of the instrumental response performed.

The restrictions in our exposition are intended to allow the development of empirical laws of performance without the prior necessity of a theory of response selection. Though the use of instrumental schedules does not guarantee that the subject will perform the response designated by the experimenter, it does make selection more likely than if the schedule did not designate an efficient response. Performance under the latter type of schedule probably would be based on mechanisms specific to an individual or species.

The paired baseline, in which both responses are freely and simultaneously available for the duration of subsequent contingency sessions, is used to determine the operant probabilities of the instrumental and contingent responses. The paired baseline provides the best estimate of what the subject would do if it were not for the schedule, and thus provides the best standard for judging the conflict imposed by the schedule.

The typical procedure of measuring only the single baseline of the instrumental response is inappropriate because it provides no estimate of the operant performance of the contingent response. It is interesting that experimenters have typically guaranteed a known relation between the baselines of the instrumental and contingent response through their procedures. For example, rats required to perform the low probabil-
ity response of bar pressing to obtain food are deprived of food, thereby ensuring a high baseline probability of eating. Such procedures can be seen as an imprecise (though convenient) substitute for the direct measurement of the paired baseline of the instrumental and contingent responses.

Response Deprivation Condition

If it is assumed that conflict between the schedule-imposed behavior and the free-responding baseline determines instrumental performance, it is important to state precisely the circumstances necessary for this conflict. The concept of response deprivation provides such a statement. For a given instrumental schedule, the condition of response deprivation is defined to occur if the animal, by performing its baseline amount of the instrumental response, is unable to obtain access to its baseline amount of the contingent response.

Eisenberger, Karpman, and Trattner (1967) defined this condition more formally. The response deprivation condition is satisfied if

\[
\frac{I}{C} \times \frac{O_c}{O_i} > 1,
\]

where \(I\) and \(C\) are the terms of the schedule, and \(O_i\) and \(O_c\) are the paired operant baselines of the instrumental and contingent responses. The \(I\) term of the schedule is the instrumental requirement for access to the contingent response, and \(C\) is the amount of access to the contingent response earned by performing \(I\).

A more easily appreciated expression can be obtained by multiplying both sides of this inequality by \(O_i/O_c\), yielding

\[
\frac{I}{C} > \frac{O_i}{O_c}
\]

as a definition of the response deprivation condition. To determine the existence of the response deprivation condition, the two responses need not be measured in identical units. It is only necessary to measure \(I\) in the same units as \(O_i\), and \(C\) in the same units as \(O_c\).

If the animal in a contingency session performs the instrumental response at or below its baseline, then Equation 1 necessitates that the contingent response be performed below its baseline. Each time the animal performs Amount \(I\) of the instrumental response, then Amount \(C\) of the contingent response, the subject necessarily performs a greater proportion of \(O_i\) than of \(O_c\). By the time the subject performs \(O_i\) of the instrumental response, it will have performed less than \(O_c\) of the contingent response.

Deprivation of the contingent response can be shown more formally by defining \(N\) as the number of times in the contingency session that the subject completes the instrumental requirement and gains access to the consequence. Total instrumental responding and total access to the contingent response in the contingency session can be approximated by multiplying top and bottom of the left side of Equation 1 by \(N\), yielding

\[
\frac{NI}{NC} > \frac{O_i}{O_c}.
\]

If the subject performs at its baseline of the instrumental response (\(NI \approx O_i\)), the numerators can be canceled and the terms rearranged to produce \(NC < O_c\), thereby demonstrating deprivation of the contingent response.

The assumption that the response-deprivation condition determines instrumental performance disagrees with Premack's contention that a probability differential between two responses is the important condition (Premack, 1959, 1965). In some circumstances, the two hypotheses make similar predictions. Many contingencies that satisfy the response-deprivation condition satisfy the probability-differential condition as well. For example, if a hungry rat must bar press to eat food (a high-probability contingent response), and the amount of food presented is small, the contingency will also deprive the subject of eating relative to its baseline. One bar press would have to produce at least 100
45-milligram pellets in order for the contingency schedule not to satisfy Equation 1 in a half-hour session (W. Timberlake, unpublished data, 1973, for 90-day-old rats at 85% of body weight).

Both approaches also predict that a contingency will increase only one of the two responses. The probability-differential hypothesis makes this prediction because only a high-probability response is assumed to be an effective contingent response. The response-deprivation approach makes the prediction on the grounds that a given contingency schedule can satisfy the response-deprivation condition for only one of two responses. This prediction can be seen by rewriting Equation 1 in terms which do not prejudge which of the two responses is instrumental and which is contingent. If

\[
\frac{A}{B} > \frac{O_a}{O_b},
\]

then it is true that

\[
\frac{B}{A} < \frac{O_b}{O_a}.
\]

In words, if the contingency schedule deprives the subject of Response B, it cannot also deprive the subject of Response A.

Despite these predictive similarities, there are differences which compel us to accept the response-deprivation condition as the more important of the two conditions. First, Premack (1965) himself showed that a schedule which did not satisfy the response-deprivation condition produced no instrumental performance despite the fact that the operant baselines of the two responses satisfied the probability-differential condition. Hence, the response-deprivation condition is necessary for instrumental performance. What Premack failed to clarify is whether the probability-differential condition is also necessary for instrumental performance (Eisenberger et al., 1967). If both conditions must be present, then instrumental performance will occur if the schedule satisfies the response-deprivation condition, even if the contingent response has the lower probability.

Eisenberger et al. (1967) attempted to evaluate these two possibilities in a series of experiments with humans. In the paired-baseline session of Experiment 4, college students were instructed to manipulate a lever, or a knob, or both lever and knob, or neither, as they saw fit. The 12 critical subjects performed both responses, but the knob response had a higher operant probability than the lever response. The baseline session was followed by a contingency session in which the opportunity to engage in the less probable lever response was contingent upon performance of the more probable knob-manipulating response. The schedule for the critical subjects satisfied the response-deprivation condition but not the probability-differential condition. The results showed that the response-deprivation condition was sufficient for instrumental performance. Despite the lower probability contingent response, subjects increased instrumental knob manipulating.

Allison and Timberlake (1974) performed a series of experiments on saccharin licking in rats which also show that the probability-differential condition is not necessary for instrumental performance in schedules which satisfy the response-deprivation condition. In one experiment rats spent more time licking 4% saccharin solution than 3% saccharin solution in paired-baseline sessions. The baseline phase was followed by contingency sessions in which the more probable response (licking 4% saccharin) was the instrumental response and the less probable response (licking 3% saccharin) was the contingent response. The contingency schedule required 80 seconds of 4% licking for each 10-second access to the 3% solution \((I = 80\text{ seconds}, C = 10\text{ seconds})\). This schedule satisfied the response-deprivation condition and produced an increase in 4% saccharin licking.

Two subsequent experiments with rats using 4% and 1% saccharin provided further evidence for the importance of the response-deprivation condition for instru-
mental performance. If the response-deprivation condition alone produces instrumental performance, then it should be possible to increase either response by changing the terms of the schedule to produce deprivation of the other. But, if the probability-differential condition is necessary for instrumental performance, then only one of the two responses can be increased unless the operant probabilities of the two responses are changed. The schedule in the first experiment deprived the subject of .4% saccharin licking and produced an increase in instrumental .1% saccharin licking. The schedule in the second experiment deprived the subject of .1% saccharin licking and produced an increase in instrumental .4% saccharin licking. These results show that the probability-differential condition is not necessary for instrumental performance, provided that the schedule satisfies the response-deprivation condition.

Timberlake and Allison (1973) showed additional support for this conclusion in an experiment, with seven female albino rats, which employed saccharin licking and wheel running as the two responses. This experiment used reciprocal schedules (Allison, 1971), which require the subject to perform a specific amount of each response in order to receive access to the other response. One schedule required 30 \( \frac{3}{4} \) turns of the wheel for access to saccharin and 10 licks to unlock the wheel. This schedule satisfied the response-deprivation condition with respect to running as the instrumental response and produced an increase in running. Another schedule required 60 licks to unlock the wheel and 5 \( \frac{3}{4} \) -turns of the wheel for access to saccharin. This schedule satisfied the response-deprivation condition with respect to licking as the instrumental response and produced an increase in licking. (See Figure 1.)

In summary, the evidence reviewed here indicates that the probability-differential condition is neither necessary nor sufficient for instrumental performance. Instrumental performance occurs only if the contingency schedule satisfies the response-deprivation condition.

**Response Deprivation and Momentary Probability Differential.**

Premack (1971) recently advanced the concept of momentary probability differen-
tional to account for instrumental performance. He has employed this concept in two contexts: in paired baseline to call attention to changes in the relative probabilities of responses during the session, and in the contingency to refer to inferred changes in relative response probabilities produced by the schedule. This section compares the concept of momentary probability differential with that of response deprivation.

Premack (1971) pointed out that in paired-baseline sessions, "... average response probabilities may badly misrepresent momentary response probabilities [p. 129]." As an example he cites data in which the probability of licking a 32% sucrose solution was higher than the probability of running during the initial part of the baseline session but lower during the latter part. Thus, according to the probability-differential hypothesis, it should be possible to increase instrumental running with contingent licking during the first part of a contingency session, while the reverse would occur during the latter part.

We agree that a complete account of instrumental performance will consider fluctuations in baseline, but it should be noted that baseline variability does not necessarily discredit predictions from the response-deprivation hypothesis. For every experiment reported in this paper, it is possible to define intervals in the baseline during which the relative probabilities of the responses reversed. Despite these reversals, the predictions of the response-deprivation hypothesis, based on average probabilities, were confirmed. Further, the response-deprivation hypothesis makes different predictions than the momentary probability hypothesis. The latter predicts reversal of the roles of the instrumental and contingent responses only if their probabilities shift during the baseline session. The response-deprivation hypothesis predicts reversal based on schedule changes alone at any point in the baseline (so long as both responses have above zero probabilities).

Premack (1971; personal communication, 1973) has also applied the concept of momentary probability differential to the contingency session, arguing that response suppression (deprivation) is simply a way of producing an eventual probability differential in favor of the contingent response. This eventual (residual) probability differential is in turn responsible for increased instrumental responding.

This application of momentary probability differential is particularly interesting because it implies that a contingent response of lower average probability can increase an instrumental response of higher average probability. If a schedule satisfies the response-deprivation condition, then each time the subject performs I and then C, the subject approaches OI more rapidly than OC. At some point in the session the subject will approach OI more closely than OC. From this point on, the contingent response will have a greater probability than the instrumental response. For this latter section of the contingency session the momentary probability-differential hypothesis predicts that the contingent response should increase instrumental responding. A numerical example of this type of contingency can be found in Table 1, Case 1.

This use of probability differs from Premack's previous procedures in that it is inferred rather than directly measured. To be consistent with his previous work, it would be necessary to measure a paired baseline at the point in the contingency session at which the momentary probabilities are assumed to reverse. Whatever the outcome of such a procedure, there are much

### Table 1

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Note. Abbreviations: O1 = baseline of the contingent response, O1 = baseline of the instrumental response, I = instrumental requirement, C = access to the contingent response.

*Number of times the subject has performed I and then C in the contingency session.
stronger reasons for doubting the efficacy of the momentary probability-differential hypothesis. Premack (1965) himself reported data which contradict the momentary probability-differential view while supporting the response-deprivation view. When a high-probability response (licking) was contingent on a low-probability response (wheel running), no increase in running occurred if the schedule did not satisfy the response-deprivation condition. Eisenberger et al. (1967) obtained similar results in their work on manipulatory behavior in humans.

The importance of these results lies in the fact that the schedules which produced no increase in the instrumental response did not satisfy the response-deprivation condition but did produce a theoretical probability differential in favor of the contingent response. A numerical example of this type of contingency can be found in Table 1, Case 2. Thus, it appears that the response-deprivation condition is distinguishable from the momentary probability-differential condition and that the evidence favors response deprivation as the more adequate predictor of instrumental performance. The probability-differential hypothesis must undergo further revision before it can account for the above data. (See Allison & Timberlake, 1974, for further discussion of this point.)

AMOUNT OF RESPONSE DEPRIVATION AND INSTRUMENTAL PERFORMANCE

To this point we have demonstrated the importance of the response-deprivation condition for instrumental performance. This section examines the possibility of a quantitative relation between amount of response deprivation and performance under instrumental schedules. As a tentative working hypothesis, we propose that amount of instrumental performance will be a monotonically increasing function of the amount of response deprivation. This hypothesis does not necessarily follow from the hypothesis that the response-deprivation condition is necessary for instrumental performance. The quantitative hypothesis depends on further assumptions concerning the way in which schedule-produced conflicts are resolved. Given the potentially complex manner in which a subject can adapt to a schedule, it seems likely that our hypothesis will not hold for all amounts of response deprivation or all types of schedules. For example, high amounts of response deprivation may produce emotional responses which interfere with instrumental performance. The primary function of the quantitative hypothesis is to provide a simple, empirically testable groundwork for the development of more complex laws of instrumental performance.

The amount of response deprivation produced by a schedule can be defined as the amount of reduction in the contingent response that would occur if the subject performed the instrumental response at its baseline level. This measure can be written as

\[
D_e = O_e - NC,
\]

where \( N \) is the largest number of repetitions of \( I \) such that \( NI \leq O_1 \). Since \( N \approx (O_1/I) \), then

\[
D_e \approx O_e - \frac{O_1C}{I}. \tag{2}
\]

It can be seen from Equation 2 that in an instrumental contingency the amount of response deprivation is an increasing function of the baseline of the contingent response \( O_e \) and the instrumental requirement \( I \) but a decreasing function of the baseline of the instrumental response \( O_1 \) and the amount of access to the contingent response \( C \). Since our working hypothesis assumes that instrumental performance

\[^* \]

\[^* \] \[D_e \] is measured in the same units as the contingent response. The instrumental response can be measured in different units because \( O_1 \) and \( I \) appear as a ratio in Equation 2, so the units cancel. However, if comparisons are to be made between the effects of different amounts of response deprivation, it will be necessary to be consistent in the measurement of instrumental and contingent responding. Expressing the same schedule in different units will change the value of \( D_e \). The prediction that instrumental performance will be a monotonically increasing function of amount of response deprivation should hold only within a set of schedules (and baselines) measured in consistent units.
is a monotonically increasing function of the amount of response deprivation, we predict that instrumental performance will be a similar function of these variables. In other words, instrumental performance should be a monotonically increasing function of $I$ and $O_e$ and a monotonically decreasing function of $C$ and $O_i$. We will review evidence for these predictions in the next few paragraphs.

**The Instrumental Requirement**

Many studies have shown that instrumental performance is directly related to $I$, the instrumental requirement for access to the contingent response. Increasing the size of the ratio in fixed-ratio schedules produces an increase in the rate of key pecking in pigeons (Ferster & Skinner, 1957) and bar pressing in rats (Boren, 1961; Collier, Hirsch, & Hamlin, 1972) and monkeys (Hamilton & Brobeck, 1964). Schaeffer (1965) varied the number of licks required for 10 seconds of running in a wheel and found that the rate of sucrose licking increased as the fixed ratio increased from 5 to 41. We have obtained similar results with instrumental licking of .1% saccharin for contingent 10-second access to .4% saccharin. Licking .1% saccharin increased as the instrumental requirement increased from 5 through 25 seconds.

Some of these studies have shown a limit to the effect of the instrumental requirement on instrumental performance. Beyond a certain point performance stops increasing or even decreases with higher instrumental requirements (e.g., Hamilton & Brobeck, 1964). A possible interpretation of such results is that other adaptive responses occur which compete with the instrumental response (e.g., emotional behavior or escape behavior). A complete account of contingency-produced behaviors must include these behaviors as well. For the present, it can be concluded that this prediction holds only within a certain range of values of $I$.

**The Baseline of the Contingent Response**

Several studies have shown that instrumental performance is an increasing function of $O_e$, the baseline of the contingent response. Premack (1963a) varied $O_e$ by varying the contingent response—running in heavy wheels or light wheels and licking various concentrations of sucrose. Instrumental bar pressing for contingent running or licking was directly related to $O_e$. Brownstein (1962), using instrumental and contingent sucrose licking in rats, and Premack (1963b), using instrumental and contingent manipulatory responses in monkeys, also found that instrumental performance was an increasing function of $O_e$. Indirect evidence also supports this prediction. For example, food-rewarded bar pressing in rats increases with food deprivation (Batten & Shoemaker, 1961)—a manipulation known to increase the amount eaten when food is made freely available (Dufort & Wright, 1962). Similarly, prefeeding the rat decreases the subsequent amount of food-rewarded bar pressing (Skinner, 1938), and we have found (unpublished data, May 1968) that prefeeding decreases the subsequent amount eaten.

**Access to the Contingent Response**

The variable $C$, access to the contingent response, has been manipulated infrequently in free-responding experiments (see Kimble, 1961). Several studies reported by Collier (1972) clearly support the prediction that instrumental performance is a decreasing function of $C$ in an instrumental contingency. Collier placed rats under a 24-hour fixed-ratio contingency schedule whereby they obtained all their food by pressing a bar. He found that the number of bar presses per day decreased as the size of the food pellet increased. Other studies have found mixed results (Kling & Schrier, 1971; Weissman, 1963); however, most of these studies have used interval schedules in which the amount of the contingent response obtained is not related to the amount of instrumental responding. The results of such schedules are not clearly predictable at the simple level on which we are employing the response-deprivation concept.
The Baseline of the Instrumental Response

The last prediction, that instrumental performance is a decreasing function of \( O_i \), the baseline of the instrumental response, has received mixed support. Holstein and Hundt (1965, Experiment 2) studied bar pressing in rats for contingent access to sucrose solution. They manipulated \( O_i \), the baseline of bar pressing, by accompanying each bar press with electrical stimulation of the brain in the high \( O_i \) condition and no stimulation in the low \( O_i \) condition. One subject showed less instrumental bar pressing under the high \( O_i \) condition than under the low \( O_i \) condition, as the hypothesis predicts. The other subject showed no difference between the two conditions.

Schaeffer (1965) reported contradictory results in an experiment on instrumental licking and contingent wheel running in rats. He varied \( O_i \) by presenting different groups with one of two different sucrose solutions, water, or an empty tube and found that instrumental licking increased as \( O_i \) increased. However, Schaeffer's procedure provided inadequate control of the instrumental requirement, \( I \). The nominal schedule (the terms stated by the experimenter) required the subject to lick five times to free the wheel for 10 seconds; however, once the animal had licked five times, it was allowed to continue licking while the wheel was free. Each time the animal completed another five licks, access to the wheel was reset for 10 seconds. Under these circumstances the subjects continued to lick following completion of \( I \); the amount of extra licking was directly related to \( O_i \) (Schaeffer, 1962). Consequently, the actual value of \( I \) increased with \( O_i \). From Equation 2 it can be seen that if the actual value of \( I \) increased at a greater rate than \( O_i \), then the amount of response deprivation also increased with \( O_i \).

In an experiment which investigated this effect, two groups of rats licked either saccharin or water as the instrumental response and received access to wheel running as the contingent response. Half of each group worked under a schedule which replicated Schaeffer's procedure by allowing the subject to terminate instrumental licking (subject-terminated requirement). The other half worked under a schedule in which the experimenter controlled \( I \) by withdrawing the tube upon completion of the requirement (experimenter-terminated requirement). The results of the first schedule were similar to Schaeffer's findings. The group with the higher baseline of the instrumental response showed the largest increase in the instrumental response. The results of the second schedule conformed to the predictions of our working hypothesis; the group with the higher baseline of the instrumental response showed the smallest increase in the instrumental response. Table 2 summarizes these data. These findings illustrate the necessity of defining the schedule precisely in order to apply the response-deprivation hypothesis.

Additional predictions can be generated from Equation 2 by manipulating combinations of the four variables on the right. At least one of these predictions is quite interesting. Since Equation 2 shows the amount of response deprivation to be dependent on the ratio of \( I \) to \( C \), identical \( I/C \) ratios should produce identical amounts of instrumental performance, regardless of the absolute values of \( I \) and \( C \). This prediction was tested in an experiment on .1% and .4% saccharin licking in rats (Allison & Timberlake, 1974). Four schedules employed different values of \( I \) and \( C \), but the \( I/C \) ratio was a constant 10 .4%licks to 1 .1% lick (\( I/C = 400/40, 300/30, 200/20 \), or \( 100/10 \)). All schedules satisfied the response-deprivation condition and produced statistically identical increases in .4% saccharin licking.
The evidence reviewed in this and the preceding sections supports the contention that response deprivation is a key condition of instrumental performance in free-responding experiments. The amount of response deprivation appears directly related to performance in instrumental contingencies. The predictions of our working hypothesis are compatible with available data and suggest new lines of research. Many of the results are not readily interpretable within the Reinforcement Model but fit nicely with an adaptive model in which instrumental performance is conceived as a response to the conflict produced by deprivation of the contingent response.

An important problem for the present approach is how to assess the baseline of a consequence not associated with a specific or easily measured response. The next section discusses this problem in the context of escape and avoidance, but our conclusions are applicable to appetitive contingencies as well.

### Escape and Avoidance Contingencies

The major problem in generalizing the response-deprivation approach to escape and avoidance behavior is that of measuring the baseline level of the contingent response. This problem occurs because the consequence is not defined in terms of a specific response but in terms of an environmental event, such as the termination of shock. Various theories assume that this environmental event is associated with certain responses, such as relief or relaxation, but these responses are either poorly specified or technically difficult to measure.

Terhune and Premack (1970) suggested one solution to this problem of baseline measurement. They measured the operant level of escape from forced running in a wheel by allowing the rat to press a bar to stop the wheel during baseline. In the contingency session the opportunity to press the bar and stop the wheel was made contingent on an instrumental licking response.

The present authors used a similar technique to measure the baseline of escape from and avoidance of shock in rats (unpublished manuscript, March 1973). In the 10-minute baseline sessions shock was turned off during the time the subject spent holding one of two bars, Bar C (an average of 594 seconds). The time spent holding the ineffective bar, Bar I, was also measured. In the contingency sessions, holding Bar C did not turn off the shock unless the subject had first held Bar I. The instrumental response was thus holding Bar I in the presence of shock, and the contingent response was holding Bar C in the absence of shock. Holding Bar I for $x$ seconds earned a certain amount of shock-free time, a constant multiple of $x$, which the subject could use by holding Bar C.

Three schedules employed $I/C$ ratios of $x/x$, $x/2x$, and $x/10x$, where $x$ was the amount of time the subject held Bar I prior to holding Bar C ($I/C = 1.0$, .5, and .1, respectively). All schedules satisfied the response-deprivation condition, and the amount of response deprivation increased with $I/C$ (see Equation 2). The predictions were that all schedules would increase the time spent holding the instrumental Bar I and that the increase would be directly related to $I/C$. Both predictions were confirmed (see Table 3). These data suggest that the response-deprivation analysis can be applied successfully.

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**Table 3**

<table>
<thead>
<tr>
<th>Subject</th>
<th>First paired baseline</th>
<th>Schedule</th>
<th>Second paired baseline</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>($I/C = .1$)</td>
<td>($I/C = .5$)</td>
<td>($I/C = 1.0$)</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>79</td>
<td>160</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>74</td>
<td>129</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>54</td>
<td>142</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>43</td>
<td>113</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>49</td>
<td>127</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>52</td>
<td>122</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>43</td>
<td>144</td>
</tr>
<tr>
<td>$Mdn$</td>
<td>1</td>
<td>56</td>
<td>134</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>52</td>
<td>129</td>
</tr>
</tbody>
</table>

**Note.** Abbreviations: $I = $ instrumental requirement; $C = $ access to the contingent response.

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8 If $O_i$ is zero, Equation 2 does not predict any effect of varying $I$ and $C$ because the term containing $I$ and $C$ goes to zero. A solution is to assume that $O_i$ is not zero but is some fraction less than one.
fully to escape and avoidance behavior by defining the contingent consequence in terms of a specific response. This approach should be generalizable to other contingencies in which the contingent response is difficult to specify (e.g., brain stimulation).

**Response Selection**

The response-deprivation analysis does not provide a complete analysis of instrumental learning but deals only with instrumental performance. In order to restrict attention to performance, it was necessary to assume that the subject was able to learn the contingency (what-leads-to-what) and perform the appropriate instrumental response. In this section we will defend these assumptions and suggest mechanisms of response selection compatible with the adaptive model.

It is easy to take for granted that the subject will perform the appropriate instrumental response in a contingency. Experimenters are skilled in choosing apparatus and contingencies which produce selection and performance of a particular response. This success appears to result from two rules of thumb. First, the experimenter makes sure that the instrumental response is the most salient and the most efficient way of gaining access to the contingent response. Second, the experimenter relates the instrumental response to the behavioral repertoire which the subject displays under the conditions of the contingency. If the rat will not lift a bar, it is required to press it or run a maze. If a pigeon will not press a bar, it is required to peck a key. The work on autoshaping of key pecking in pigeons and bar manipulation in rats highlights the ability of experimenters to hit upon instrumental responses that are closely related to the animal's ready-made repertoire (Brown & Jenkins, 1968; Moore, 1971; Peterson, Ackil, Frommer, & Hearst, 1972; Staddon & Simmelhag, 1971). In the case of key pecking and bar manipulation, instrumental-like responses appear to be elicited directly by cues which predict the delivery of the consequences. Failure to use such highly "prepared" responses (Seligman, 1970) may result in great difficulty in learning (Bolles, 1970, 1972; Breland & Breland, 1961, 1966; Shettleworth, 1972).

From the success of these two rules in determining the instrumental response, it is possible to infer the existence of two related mechanisms of response selection. These response-selection devices can be characterized as (a) a comparator mechanism which selects the response most efficient in gaining access to the consequence, and (b) a set of species-typical response mechanisms which result in instrumental-like anticipatory responses to cues predicting the consequence. Both types of devices can be viewed as comparators. The first is an efficiency comparator promoting individual survival. The second is a phylogenetic comparator promoting species survival. These mechanisms act simultaneously. They may select the same response (as in fixed-ratio key pecking in the pigeon), or they may select conflicting responses (as in omission training in autoshaping; Williams & Williams, 1969). Whatever the contingency, response selection should be the result of an interaction between these two types of mechanism.

This brief discussion of response-selection mechanisms should support our contention that the factors which determine response selection can be partly isolated from those which determine performance. The adaptive model and the response-deprivation approach are compatible with ethological, cognitive, and information-processing approaches to response selection.

**Application Notes**

The following application notes will make explicit some of the experimental procedures and assumptions underlying the present approach.

**Baseline Assessment**

We assumed that the prediction of instrumental performance depends on the accurate measurement of the instrumental and contingent responses in a paired-baseline session. The paired-baseline assessment was chosen on the grounds that it provided the
best estimate of what the subject would do if it were not for the constraints imposed by the schedule. By referring to paired-baseline responding, it should be possible to discover the degree of conflict produced by imposing the schedule.

An alternative to the paired-baseline procedure is the measurement of two separate baselines, one for the instrumental and the other for the contingent response. However, in our opinion the use of two single baselines does not allow as accurate a judgment about the conflict imposed by the schedule as does the paired baseline. In single-baseline sessions the instrumental or contingent response competes for expression only with activities such as exploration, pausing, or grooming. In paired-baseline sessions the instrumental and contingent responses must compete for expression with each other as well. To go from single-baseline sessions to the contingency involves two types of conflict, one imposed by the necessity of two responses sharing the same time period, and the second imposed by the terms of the schedule. The use of paired baseline resolves the time-sharing conflict prior to imposing the schedule, thereby allowing a better estimate of the effects attributable to the schedule alone.

This conclusion does not eliminate the use of other baselines. The response-deprivation condition, defined in relation to the paired baseline, produces a conflict which is probably resolved by a combination of adaptive reactions. We have referred to these reactions collectively as instrumental performance. However, a more complete analysis would begin to divide instrumental performance into several components by employing different baselines, control groups, and measures. In such a task, there is no one baseline, control group, or measure that is appropriate to the analysis of all components of instrumental performance (cf. Seligman, 1969). Each procedure allows the assessment of different aspects of adaptive behavior. We have chosen the paired baseline as a starting point because it appears best suited to define the conflict imposed by a schedule.

The Schedule

To apply our analysis accurately, it is important that the nominal schedule (the one stated by the experimenter) reflect the schedule performed by the subject. The most typical discrepancies between nominal and actual schedules involve greater than I amount of instrumental responding (the subject overshoots the requirement) or less than C amount of the contingent response (the subject fails to use all access time to the contingent response). Neither effect is damaging to most predictions since both errors increase the size of the nominal I/C ratio, thereby leading to the prediction of a larger increase in instrumental responding than would be anticipated from the assumed schedule.

However, as shown by Schaeffer's (1965) results, the difference between nominal and actual schedules can be very important. The strictest control of the schedule parameters is provided by a reciprocal schedule (Allison, 1971) in which the subject must perform amount I to gain access to the contingent response and then perform amount C of the contingent response in order to regain access to the instrumental response. This schedule ensures that the assumed ratio and the actual ratio experienced by the subject are identical.

One other obvious limitation is that neither I nor C be larger than the animal can perform. Changes in very large I or C values would be expected to have no effect on performance.

A general limitation of the schedules in this paper was their restriction to instrumental schedules—those in which the amount of performance of a clearly defined instrumental response is directly related to the amount of the contingent response obtained. There are many schedules, some quite popular in the literature, which do not meet this test (e.g., variable-interval and fixed-interval schedules). The adaptive model can still be applied to these schedules because they may impose a conflict with baseline responding. The conflict is not easily measured in advance but does depend on the difference between the amount
of contingent responding allowed in the contingency and the baseline amount of contingent responding \((O_c - NC)\). Clear predictions of performance are more difficult than in instrumental contingencies because no efficient instrumental response is available. The performance of the subject will probably be based on species-typical responses to predictive and frustrative cues.

A related difficulty in applying the present approach occurs when noninstrumental responses available to the subject present the possibility of an alternative resolution to the contingency-imposed conflict. For example, W. McIntosh (unpublished data, August 1972) recently tested the effect of a freely available \(0.1\%\) saccharin solution upon a rat's instrumental nose poking for access to a \(4\%\) saccharin solution. When the \(0.1\%\) solution was absent, the subject increased instrumental nose poking over baseline. However, when the \(0.1\%\) solution was available the subject licked it rather than perform the nose-poking response for access to the \(4\%\) solution. A complete account of contingency-produced behavior must include considerably more complexity than the present instrumental version of the response-deprivation analysis.

**Summary**

Some consequences increase the probability of instrumental responses which they follow, and other consequences do not. The empirical law of effect has been used to distinguish these consequences but in a post hoc fashion. The empirical law of effect is challenged as an unfinished step in the development of empirical laws; it is shown to make incorrect predictions and to be closely related to an untestable model of instrumental learning, the reinforcement model.

We suggest that the empirical law of effect and the reinforcement model should be abandoned, and instrumental learning should be separated into several different processes rather than united with one strengthening process. We focus on the prediction of instrumental performance and develop the adaptive model and the concept of response deprivation to account for instrumental performance. The adaptive model views instrumental performance as the result of conflict between baseline responding and the response relations imposed by the schedule. Response deprivation represents a way to quantify the amount of conflict produced by an instrumental schedule.

The data reviewed from free-responding experiments showed that instrumental performance is generally a direct function of the amount of response deprivation, no matter how it is produced. The response-deprivation analysis can be generalized to escape and avoidance contingencies and is compatible with several models of response selection. We conclude that response deprivation is an important and quantifiable determinant of instrumental performance.

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ERRATUM

In the article by Martin Fishbein and Icke Ajzen in the January 1974 issue, on Page 70 Lines 10-16 of the right-hand column should read as follows:

However, it should be noted that there is no direct relation between the validity index and the linearity index. Specifically, the linearity index, that is, \(| p(B|A^+) - p(B|A^-) |\), is a function not only of the validity index but also of the values of \(p(A^+|B)\) and of \(p(B)\).