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Contiguity and Contingency in Instrumental Conditioning

GLYN V. THOMAS

University of Birmingham

There have been several attempts to construct molar theories of conditioning on the empirical basis that response–reinforcement contingency is important in determining conditioning. Such theories claim to explain behavior in terms of molar level processes which transcend the molecular level and, therefore, are not reducible to molecular processes or their interaction. These molar theories are critically examined and found to be seriously flawed because they fail to account for the effects of delaying reinforcement (degree of contiguity). Observed molar level relations, such as the matching law, do not require a molar theory, but may be more usefully considered as a product of molecular processes.

Much recent work on reinforcement and instrumental conditioning has sought to establish molar laws of behavior. These efforts have produced important empirical generalizations, such as the matching law and its derivatives. A molar analysis is, essentially, a large scale analysis. Molar principles of reinforcement, for example, disregard individual responses and rewards; instead, they describe relations between large numbers of responses and reinforcements integrated over substantial periods of time.

It is possible that these molar analyses stem ultimately from Skinner's early emphasis on response rate as a dependent variable (Skinner, 1938). It is certainly true that current molar analyses are frequently associated with other features of Skinnerian Psychology; single-subject methodology and descriptive theories of behavior. Many, if not most, papers on this molar approach to reinforcement have appeared in the *Journal of the Experimental Analysis of Behavior*. And some recent issues of that journal have been dominated by molar analyses of response–reinforcement relations in choice experiments.

The principal molar level relation under study has been called the matching law. This law asserts that, in a choice experiment, relative rate

The author thanks David Booth for his advice and encouragement. Requests for reprints should be sent to Glyn V. Thomas, Department of Pscyhology, University of Birmingham, P.O. Box 363, Birmingham B15 2TT, England.

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of responding will match relative rate of reinforcement for each choice. This matching principle appears to have wide generality and its importance and its molar nature have been stressed by many authors (e.g., Baum, 1973; Bloomfield, 1972; Herrnstein, 1970; Keehn, 1972; Rachlin & Burkhardt, 1978; Rachlin, Battalio, Kagel, & Green, 1981; Staddon & Motheral, 1978).

Encouraged, perhaps, by the success of the matching law at an empirical level, some authors have proposed molar theories of behavior. I am concerned here with theories of the kind that Mackintosh (1983) has called "contingency" theory and Williams (1983) has called "correlation" theory. An early and influential proponent of correlation theory was Baum (1973) who proposed a molar law of effect.

To some degree, these correlation theories of behavior and reinforcement can be characterized as a reaction to limitations in traditional theories of instrumental conditioning (Hull, 1943; Skinner, 1938; Spence, 1956; Thorndike, 1911). The traditional theories stressed the importance of the contiguity of discrete responses and rewards, and thus could be described as molecular analyses. There is now, however, much evidence that simple temporal contiguity is an inadequate basis for conditioning.

In considering the development of molar theories, one of the main limitations of simple contiguity analyses is their failure to account for the effects of response–reinforcement contingency—the effects quantified by the empirical matching law. Many studies have shown that the effect of reinforcement for a given response is reduced if additional reinforcers are given for other behaviors or are given independently of behavior (deVilliers & Herrnstein, 1976).

Correlation theories embody the belief that the limitations of traditional contiguity theories can be circumvented by treating behavior at a molar level. It is this move to a molar level that I wish to critically examine. The focus of my discussion is on the general issues raised by treating reinforcement and conditioning at a molar level rather than on any one particular molar theory. We should note that some of the processes invoked to explain behavior can be the same at both molar and molecular levels of analysis. Thus, for example, we have been offered both molar and molecular theories of reinforcement maximization (Shimp, 1969; Staddon & Motheral, 1978, respectively).

The Question of Assessing Contingencies

The fact that contingency is important empirically does not force us to conclude that learning must fundamentally be a molar process, and therefore that organisms must be able to sense contingencies or correlations directly (Rachlin, 1976). Molar level relations between behavior and reinforcement could also be derived from a combination of molecular effects. This latter view is the one taken, for example, by Shimp (1969), and by

Silberberg, Hamilton, Ziriax, and Casey (1978); they claim that observed molar level matching of response and reinforcement rates on concurrent schedules is a byproduct of molecular processes such as reinforcement maximization and response perseveration.

Correlation theories, however, assert or imply that organisms are directly sensitive to relations between behavior and reinforcement at a molar level. It is fundamental to this position that molar relationships are not derivatives of molecular processes.

> ". . . the molar matching law is . . . a general law of behavior, not an artifact or byproduct of more molecular processes." (Nevin, 1979, p. 305).

A similar view is implied when molar theories are claimed to be superior *alternatives* to analyses at a molecular level.

The Problem of Assessing Rates and Correlations

It may be regarded as a weakness in molar correlation theory that few of its proponents have seriously addressed the question of how it is that subjects make contact with molar level variables such as response and reinforcement rates. Baum (1973) has provided one of the few clear accounts of how molar level variables and relationships might be detected by subjects. Consider a subject making discrete responses and receiving occasional reinforcements. Baum (1973) argued that assessments of response and reinforcement rates, and the relation between them, can be made by comparing the numbers of responses and reinforcements in successive time samples during an experimental session. Baum's position is that the correlation of response and reinforcement rates is the fundamental contingency of reinforcement (and implied in this view is the claim that molecular processes are of little or no importance).

A positive correlation between response and reinforcement rates requires that responses and reinforcements be grouped together in the time samples (see Fig. 1). For any given pattern of responses and reinforcements, however, the extent of the derived correlation can also depend on the size of the time sample (see Fig. 2).

One problem with these proposals is that the subject's task in correlating rates of responding and reinforcement is improbably complex, particularly when the analysis goes beyond the simple, single-response case. Consider a typical concurrent schedule experiment with two operant responses, each with its own independent schedule of reinforcement. Matching of responding with relative reinforcement rate, according to Baum's proposals, requires the subject to detect the correlation between the rate of each of the responses with the relative rate of reinforcement for that response, sampled over several time periods. It is pertinent to ask how the subject knows which of the reinforcements to allocate to each response in cal-

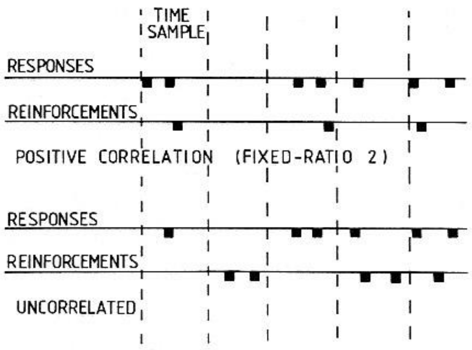

FIG. 1. Responses and reinforcers must be grouped together in the time samples for a positive correlation between response and reinforcement rates.

culating the correlations. In most experiments of this kind, the reinforcements for both responses are identical amounts of food, and so cannot be distinguished intrinsically. The obvious alternative, to classify each reinforcement according to the response with which it was contiguous, would, however, introduce a molecular factor and thus vitiate the molar character of the theory. It seems unparsimonious and unlikely that subjects should disregard the information provided by response–reinforcement contiguity and, instead, should perform an apparently complex integration of rates of responding and reinforcement over several time periods. Nevertheless, that is exactly the task of sampling molar variables that Baum's proposals set for the organism.

The Problem of Separating Contiguity and Correlation

It is not easy to provide a direct experimental test of the importance of molar versus molecular factors. In most instrumental conditioning procedures, molecular level contiguity and molar level correlations are confounded. Delaying reinforcement has effects—impeding learning and reducing response rates—which seem to suggest the importance of molecular contiguity. Delaying reinforcement, however, can also reduce the

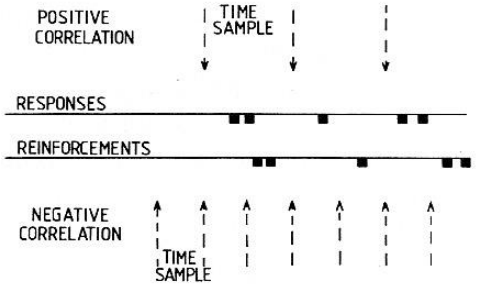

FIG. 2. For a given grouping of responses and reinforcements, the extent of the derived correlation between them can depend on the size of the time samples.

correlation of response and reinforcement rates by loosening the temporal grouping of responses and reinforcements (Baum, 1973).

Similar difficulties arise when data seeming to support the molar contingency position are examined more closely. In many operant conditioning experiments on intermittent schedules of reinforcement, it has been found that response and reinforcement rates are positively correlated (see, for example, Herrnstein, 1970). These data, however, can also be interpreted in terms of contiguity; lower reinforcement rates result in lower response rates, for example, since less frequent reinforcements introduce more opportunities for unreinforced responses: i.e., responses with poor contiguity with reinforcement.

There is a logical aspect to this design problem (Thomas, 1981). A molar contingency, or correlation, by definition must make some reference to the temporal relations (i.e., degree of contiguity) between individual responses and reinforcements. Similarly, any arrangement of a series of events at a molecular level in which responses and reinforcers occur in some degree of molecular contiguity will also inevitably yield a correlation between molar rates of responding and reinforcements.

Long-Term versus Short-Term Factors

Nevertheless, it does not follow from the foregoing argument that we can never disentangle molecular and molar variables experimentally. Consider the argument that the one crucial distinction between them is the *time span* over which contingencies are calculated. Molecular analyses are concerned with momentary events, such as conjunctions of individual responses and reinforcers. Molar analyses are concerned with the rates at which events occur over time. It makes sense, in fact, to talk of rates of occurrence only over substantial periods of time (see Baum, 1973).

Indeed, some of the strongest empirical support claimed for molar analyses comes from the fact that, when measurements are taken over substantial periods of time, they then yield more orderly relationships than do molecular analyses (Honig, 1966). Furthermore, there is an impressive degree of uniformity in such relations as matching between response rate and relative reinforcement rate (Herrnstein, 1970).

Thus, I suggest that an essential difference between molar and molecular analyses is the time span over which behavioral contingencies are to be effective. In that case, molar analyses could be described as long term, and molecular analyses as short term. A possible empirical test of the relative importance of long-term (i.e., molar) and short-term (i.e., molecular) contingencies would be to set short-term contingencies against long-term contingencies.

Thomas (1981) reported two experiments which achieved this opposition by providing rats with lever responses having both short- and long-term consequences. The principal feature of Experiment I was that, in the absence of any lever responding, "free" food pellets were delivered to the rats at 20-sec intervals. In any given interval, a response on the lever produced an immediate pellet of food (thereby introducing response–reinforcer contiguity), but also cancelled some of the following "free" reinforcements (thereby eliminating any positive correlation between overall rate of lever responding and overall rate of food reinforcement). Any further responses after the first, reinforced, response in each 20-sec interval had no programmed consequences. The results of this experiment (Fig. 3) show that responding was readily established and maintained in all six subjects tested.

Experiment II (Thomas, 1981) was similar to Experiment I except that

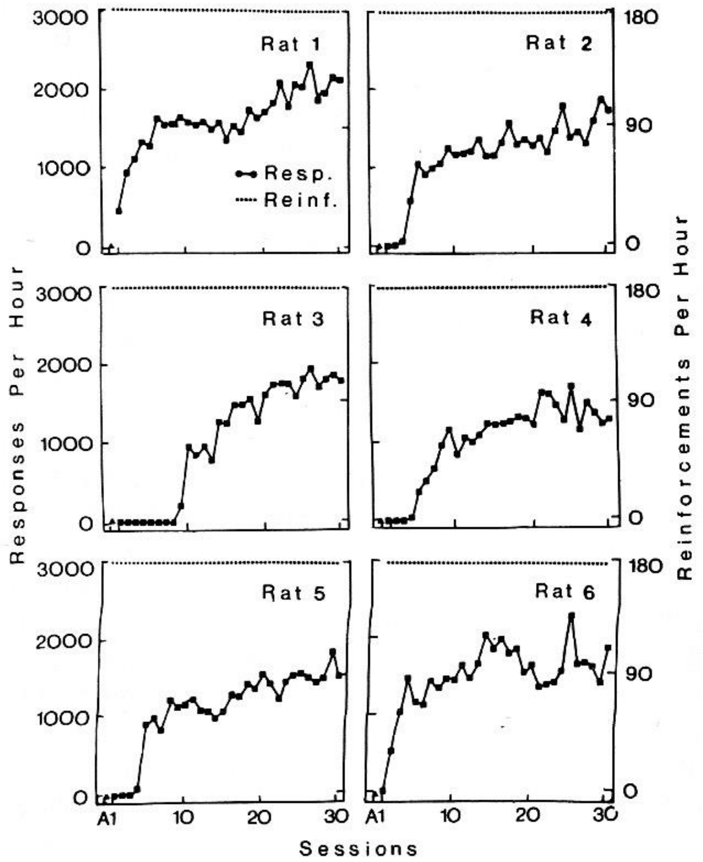

FIG. 3. Overall number of responses per session for each rat in Experiment I (solid lines, filled circles). The overall number of reinforcements per session (both "free" and response-produced reinforcements) are shown by the dashed lines. The mean unconditioned rate of responding during the 10 adaptation sessions is shown by the filled triangle at A. In Experiment I the first response in each 20-sec interval produced an immediate food reinforcement but cancelled the free reinforcement that would otherwise have come at the end of that interval. Consequently overall rate of reinforcement was unchanged by responses. From Thomas, *Quarterly Journal of Experimental Psychology*, **33B,** 33–43. Copyright 1981 by the Experimental Psychology Society.

each reinforced response cancelled *two* of the following free reinforcements, thus yielding an inverse relationship between overall response rates and overall reinforcement rates. In other words, responding on the lever in Experiment II actually reduced the overall rate of reinforcement. The results of this experiment (shown in Fig. 4) again appeared to support the contiguity position; responding was established and maintained in all subjects despite the loss of reinforcements it entailed.

On the face of it, these results strongly suggest the importance of molecular contiguity over molar contingency. However, the above results can be regarded as unsurprising if you consider the procedure in both

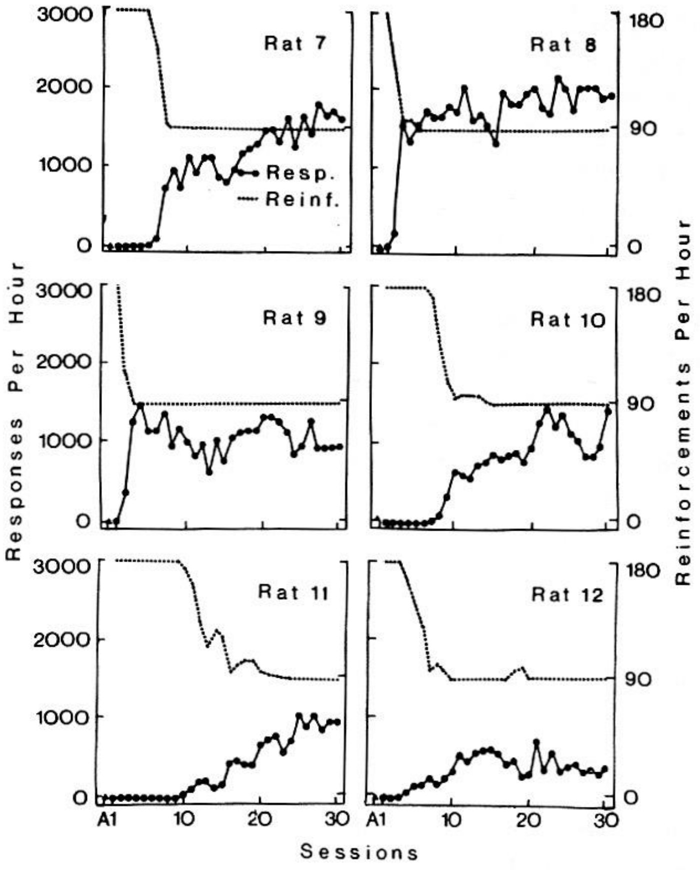

FIG. 4. Overall number of responses per session for each rat in Experiment II (solid lines, filled circles). The overall number of reinforcements per session (both free and response-produced reinforcements) are shown by the dashed lines. The mean unconditioned rate of responding during the 10 adaptation sessions is shown by the filled triangle at A. In Experiment II the first response in each 20-sec interval produced an immediate food reinforcement, cancelled the "free" reinforcement that would otherwise have come at the end of that interval, and postponed by 20 sec the start of the next interval. Consequently, responding reduced the overall rate of reinforcement. From Thomas, *Quarterly Journal of Experimental Psychology*, **33B**, 33–43. Copyright 1981 by the Experimental Psychology Society.

experiments as offering a choice of two behaviors: responding on the lever and not responding. At all times, responding would lead to food after a shorter delay than not responding and so the results simply confirm the well-known finding that immediate reinforcement is normally preferred to delayed reinforcement (e.g., Rachlin & Green, 1972).

What is, perhaps, surprising is that the difficulties created by studies such as that by Rachlin and Green (1972) for any molar theory have not apparently received more attention. We shall now consider two modifications to the molar position that could be used to attempt to explain the facts of performance attenuation by delay of reinforcement.

One argument depends on the notion that delaying reward is functionally equivalent to reducing its magnitude (Baum & Rachlin, 1969). Thus, in Experiment I above, subjects would be said to have indicated a preference for the package of food followed by a delay over an alternative package of a delay followed by food (see Rachlin *et al.*, 1981). The main difficulty lies in the fact that the alternative packages are distinguishable only in their internal molecular structure. In the long-term perspective of a molar analysis, the two packages should be the same.

Another objection to the package notion is the degree of arbitrariness involved in defining the packages. The lack of clear and justifiable rules for defining the functional limits of each package seriously detracts from the rigor and precision of the account. Rachlin *et al.* (1981, p. 386) assert that "a molar maximization theory predicts maximization over the time being considered." The crucial point is that we need to know, from the subject's point of view, what the time span being considered comprises before the molar theory can be tested against molecular alternatives.

The second argument that might be used to provide a molar account of the effects of delay of reinforcement is to suggest that the time samples used for assessing response and local reinforcement rates are sufficiently short (less than 20 sec in the experiments above) to yield the necessary positive correlation between response and relative reinforcement rates to preserve the molar position. The difficulty here is that reducing the duration of the time samples removes the one distinction defining the molar position as different from a molecular analysis. The shorter the time samples become, the more and more similar to the contiguity position does the molar account become.

Before leaving discussion of these experiments entirely, it is perhaps worth mentioning one respect in which the results are surprising. In Experiment II, all subjects could have gained twice as many rewards as they actually received if they had worked less, i.e., if they had not responded at all. It is true that some studies have found that rats may "work" for response-produced food even when identical food is freely available. Any such preference for response-produced food, however, is relatively slight and only operates when work demands are low (e.g., fixed-ratio 2). Carder and Berkowitz (1970) found that, with higher ratios, free food was preferred. In the experiments in question (Thomas, 1981), the response-to-reinforcement ratio was frequently more than 10 to 1 in the final performances. Therefore, it is most implausible to consider that a preference for earned food could have obscured the effects of response–reinforcement rate correlation in this study.

We are left, then, to conclude that the subjects in these studies took a very short-sighted view of life. Indeed, nearly all choice studies involving delay of reinforcement (e.g., Rachlin & Green, 1972) have found that immediate rewards are preferred over delayed rewards—even when the latter are larger (or more frequent). This myopia is not exclusive to rats and pigeons. Human adults and children often show a similar preference for immediate rewards (e.g., Irwin, Armitt, & Simon, 1943; Irwin, Orchinik, & Weiss, 1946; Mischel, 1958).

A short temporal horizon is not necessarily counterfunctional nor even irrational, however. In a real world, there may indeed have been a selective evolutionary advantage in securing an immediately available reward rather than deferring responding for a future reward that may recently have been more probable or larger, but whose contingency (sic) may change during the wait. A bird in the hand is frequently worth two in the bush (or in the future). In human cognitive terms, therefore, the reasons for a short temporal horizon may well be related to the lifetime certainty (sic!) of gaining delayed rewards (cf. Mahrer, 1956).

The facts of delay of reinforcement, then, turn out not to be as easily accommodated within a molar contingency position as Baum (1973) suggested. One of the virtues of the procedures studied by Thomas (1981) is that they illustrate this problem particularly clearly.

Learning and Performance

One move which might be used to preserve the molar contingency view is to suggest that the molar analysis applies to *performance* but that molecular considerations, such as contiguity, are important in *learning*. It could be claimed that subjects are generally sensitive to molecular contiguity when they learn about the outcomes of their behavior and that this learning is then translated into performance governed by molar contingencies. There are several grounds for viewing this proposal with suspicion. The main problem must be the fact that subjects in the experiments discussed above (Thomas, 1981) *performed* in accord with molecular, rather than molar considerations.

It is correct, however, to say that most molar contingency theories have been applied to steady state performance, (e.g., Rachlin *et al.*, 1981; Staddon & Motheral, 1978). Nevertheless, none of these theories has, to my knowledge, explicitly excluded acquisition of performance from consideration. Furthermore, it does not seem to me to be very likely that the factors governing steady state performance would be totally different from those affecting the attainment of that steady state and vice versa. To make such a distinction solely because it would ease some problems for molar analyses seems to me to be very post hoc and not at all persuasive.

Avoidance

Avoidance has long been thought to pose special problems for any molecular analysis in terms of response–reinforcer contiguity. The main point of concern here is the fact that the reinforcement in avoidance is usually the omission of an aversive stimulus, and consequently there is no discrete external event which occurs in contiguity with the avoidance response. Some avoidance procedures provide an external warning signal which ends on the occurrence of the avoidance response (thus introducing a form of contiguity), but some procedures do not (e.g., Sidman, 1953).

One molecular explanation of unsignaled avoidance is based on the notion of internal warning signals—conditioned aversive temporal stimuli (CATS)—which are claimed to function in much the same way as the external warning signals in traditional discriminated avoidance procedures (Anger, 1963).

There are often, it is true, difficulties in independently verifying the occurrence and function of such CATS; such difficulties have been heavily stressed by some critics of the molecular position (e.g., Herrnstein, 1969; Herrnstein & Hineline, 1966). Nevertheless, the idea that such CATS could occur as a bridging mechanism in avoidance is a plausible one, and there is other evidence suggesting that such internal clock stimuli may gain control over behavior (e.g., temporal conditioning, Pavlov, 1927). Furthermore, if the notion of internal temporal stimuli is objectionable in the context of avoidance, then it should also be objectionable in other contexts such as positive reinforcement. Curiously, appeals to internal temporal stimuli in the control of fixed-interval schedule performance have never drawn such strong criticism.

Moving now to an empirical level, it is clear that a molecular contiguity analysis of avoidance does require that an avoidance response increase the delay to the next shock. In contrast, molar theories have stressed the importance of the reduction of overall frequency of shocks normally produced by avoidance responding. In conventional avoidance procedures, the two effects—increased delay and reduction of shock frequency—are usually confounded. A close parallel is obvious with the analysis of positive reinforcement discussed above.

In a well-known attempt to distinguish between the molecular contiguity and molar positions, Herrnstein and Hineline (1966) found that rats could learn to respond on a procedure which reduced overall shock frequency, but did not eliminate shocks entirely. Although performance on this shock frequency reduction procedure has been widely cited and used to argue in favor of a molar view, the data are in fact not at all decisive. The results could be explained in terms of contiguity, because, on average, responding increased the delay to the next shock even though it did not eliminate shocks entirely.

Subsequent authors have been more successful at separating the effects of delay of shock and shock frequency reduction in avoidance: but not all have come to the same conclusions. Several studies suggest the importance of the delay from response until the next shock and thus support a molecular contiguity account. Bolles and Popp (1964) found that a modified avoidance procedure in which responses reduced shock frequency but did not delay shock failed to generate responding. Hineline (1970) found that with a discrete trials procedure, rats would bar press for increased delay to shock without changes in overall shock frequency. Gardner and Lewis (1976) found that rats would respond to delay shock, even when overall shock frequency was increased threefold.

Two studies, however, provide support for the opposing molar position. The Hineline (1970) study mentioned above found that responding was not maintained when responses increased shock frequency as well as delaying shock. Lambert, Bersh, Hineline, and Smith (1973) investigated a procedure in which a response produced one shock immediately (reduced delay) but avoided a series of five shocks up to 10 sec later (shock frequency reduction). Lambert *et al.* found that responding could be generated by this procedure only in some circumstances.

As with positive reinforcement, the temporal parameters seem to be important. Both Hineline and Lambert *et al.* used procedures in which the reductions in shock frequency occurred over the 10-sec period immediately after the response. In contrast, Gardner and Lewis (1976) found acquisition of responding with delayed shock but with increased shock frequency, measured over time samples of 150 sec or more. A molar shock frequency account, therefore, could explain the Gardner and Lewis result only by assuming that the time samples over which frequencies were calculated were shorter than the 150-sec delay interval (see above). However, the assumption of short time samples seems to me to undermine the molar basis of the analysis. Just as with positive reinforcement, if the time sample has to be assumed to be short to sustain a molar analysis in terms of shock frequency then, in my view, the analysis has become more like a molecular account than a molar one.

On balance, then, the evidence from avoidance supports conclusions parallel to those drawn from positive reinforcement. Short-term (molecular) considerations relating to contiguity, immediacy of reward, and delay of shock seem to be more important than molar changes in overall frequency of reward or frequency of shock when they are measured over substantial periods of time.

Conclusions

Molar correlation theories are, I submit, inadequate because they cannot account for the effects of response–reinforcement contiguity. Observed molar level relations in instrumental behavior, such as the matching law, seem to me to be most usefully considered as byproducts of molecular level processes (Shimp, 1969; Silberberg *et al.,* 1978). There is a close parallel in the case of classical conditioning, where Rescorla and Wagner (1972) have produced a powerful molecular level theory (based on contiguity) for analyzing the effects of molar contingency.

The separation of molar and molecular positions has some of the appearances of a paradigm clash (Kuhn, 1962). The opposing traditions favor different publications (*Journal of the Experimental Analysis of Behavior* and *Journal of Experimental Psychology*) and cross referencing is infrequent. The molar approach is linked closely with single-subject methodology and Skinnerian philosophy, which has long been noted for its relative isolation (see Krantz, 1971).

Within the operant tradition, molar correlation theory is still a powerful influence. Many of its proponents acknowledge the necessity to reconcile molar level considerations with the molecular level (e.g., Herrnstein, 1979). But this acknowledgment does not seem to have had a significant impact on the direction or tenor of molar level theory or research. Despite its serious flaws (see above), molar correlation theory is still presented as a superior *alternative* to molecular level approaches (e.g., Nevin, 1979; Rachlin *et al.,* 1981). In addition to the flaws discussed above, molar correlation theory is silent on many phenomena at a molecular level, such as response overshadowing (e.g., Pearce & Hall, 1978) and marking (e.g., Lieberman *et al.,* 1979). There is much of importance to investigate in behavior at a molar level. But the existence of significant relationships such as molar matching does not require us to adopt molar theories of conditioning. Molar correlation theory cannot yield a more fundamental and superior analysis to that possible at a molecular level, because it cannot account for all the facts. It is unfortunate, therefore, to talk of molar analyses superceding or transcending molecular concerns.

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