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The effects of a negative contingency between response rate and reinforcement rate on rate of responding

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The University of North Carolina at Greensboro, 1987

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The Effects of a Negative Contingency Between Response Rate and Reinforcement Rate on Rate of Responding

by

Debra J. Spear

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If the molar dependency between response rate and reinforcement rate can affect response rates, then responding should decrease when subjects are presented with a schedule which produces a negative contingency between response and reinforcement rates. Six pigeons were presented with concurrent linear variable-interval schedules with equal rates of reinforcement on the keys and where uncollected reinforcements were stored while the schedule progressed. This schedule results in a near zero correlation between response rate and reinforcement rate. During some conditions reinforcements were subtracted from the store when a fixed number of responses occurred on one of the keys, resulting in a negative correlation between response and reinforcement rates. Three variable-interval values, 30 seconds, 45 seconds, and 60 seconds, and four subtractive fixed ratio values, 5, 10, 20, and 60 were studied. An effective molar contingency should have produced a response distribution where responding was lowest on the subtractive fixed ratio component, but response rates remained equal on both keys. The effects of a two-second delay imposed between responses on one key and reinforcement for responses on that key were also studied. During these conditions response rates on the delay key did

differentially decrease. These results suggest that the molar dependency is not an effective contingency for controlling response rates, while contiguity between a response and a reinforcer is an effective contingency for modifying responding.

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INTRODUCTION

Adaptation to the environment requires that the relationship between an organism's behavior and it's consequences effectively modify the behavior. The study of contingency-controlled behavior makes this relationship explicit. When a dependency exists between what the organism does and environmental changes, this dependency can affect future behavior. It would be naive to assume that only a single response property is affected by a particular contingency. It seems more reasonable to assume that several response properties are shapable by the prevailing contingencies. For example, when learning to read, pronounciation and meaning of individual words are taught, yet most readers settle on one particular speed of reading. This may be the result of some other contingency (such as ease of comprehension, rate of getting through the material, etc.) shaping another response dimension.

One contingency that has been shown to be effective is close temporal contiguity between a response and its consequences. This contingency is the basis for Thorndike's Law of Effect and much of Skinner's work on schedules of reinforcement. Another proposed contingency is the molar dependency between response rates and the resulting reinforcement rates. Of particular importance is the question of whether response rate is a shapable response dimension or whether response rate is an indicator of the strength of the response due to response-reinforcer contiguities.

The possibility that response rate can be directly shaped could have impact on current theories of behavior for at least two reasons. First, if, at any time, it can be shown that response rate is a shapable unit of behavior, then principles of behavior based on maintaining contiguity between individual key pecks and reinforcement cannot be true for all contingencies. In traditional accounts, the effectiveness of response-reinforcer associations is thought to depend on the delay between a response and its consequences, where the shorter the delay, the more effective is the reinforcer in strengthening that response. Temporal contiguity means that the time between a response and a reinforcer is the primary determinant of response strength as reflected in emission rate. However, delay of reinforcement is meaningless when rate of responding is the response unit with rate of reinforcement as the effective contingent dimension because the rates do not have a precise temporal locus between which to measure delays.

The second reason that an effective molar contingency could be important is because it draws attention to the possibility that discrete responses may not be the only behavior which can be directly controlled. Response rate is most often thought of as a measure which can imply the current strength of individual behavioral units (cf., Zeiler, 1977). It is rare that response rate is thought of as a functional response unit. If both response rate and individual responses can be simultaneously modified by separate contingencies, then schedules which produce several contingencies congenial to the strenghtening and the shaping of many behavioral properties may produce a particular response rate due to the combination of these contingencies. Such compound effects could cause serious problems for quantification of the relationship between reinforcement variables and response strength if contingencies other than temporal contiguity were ignored. It would be essential to separate the effective and non-effective dimensions of each contingency to see their independent effects. Is rate a shapable dimension of behavior, or is it an index of the effectiveness of a contingency which selects a temporally discrete response?

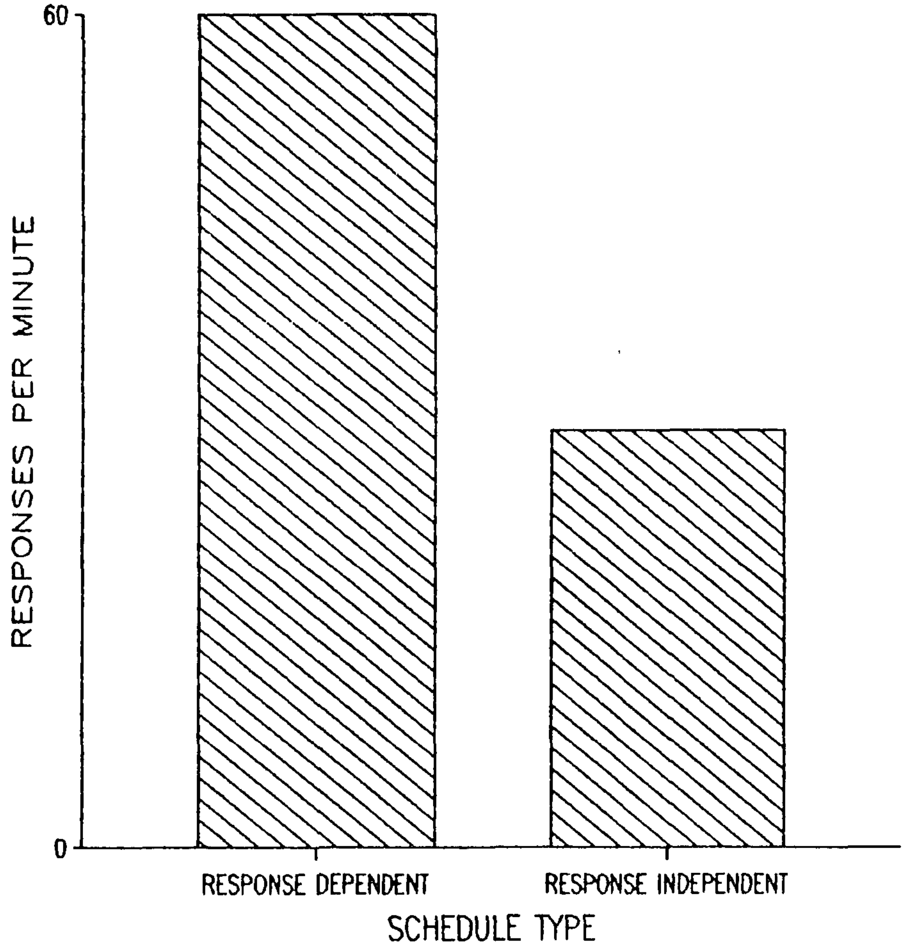
TEMPORAL CONTIGUITY

Catania (1984) has provided guidelines for demonstrating the efficacy of a contingency. First, a contingency must be arranged between some property of behavior and some dimension of reinforcement. Reinforcement is available for emitting that response but not for emitting any other response. This schedule of reinforcement should then produce an increase in the probability of the properties of the behavior on which reinforcement is dependent, if the contingency has been effective. If the probability of this property of behavior does increase, then it remains to be shown that it was the contingency, and not some other aspect of this new situation, which increased the rate of behavior. One way to show that it was the contingency which changed behavior is to take the contingency out, leaving all other factors of this new situation intact. That is, continue to deliver the reinforcer, but do so independently of that property of behavior. The removal of an effective contingency should result in a decreased probability of that property of the behavior. If the probability of that aspect of behavior does not decrease, then some other aspect of the environment which accompanied the introduction of the contingency must be responsible for the observed change in rate.

If grain presentation is an effective reinforcer, then a contingency in which grain is presented only after a pigeon's key peck should result in an increase in key pecks. Catania and Keller (1981) have provided a clear demonstration of the effectiveness of a contingency based on the contiguity between a key peck and grain delivery (although this was not the first demonstration). The first key peck which was emitted after one interval of the schedule (mean = 60 seconds) since the last grain delivery was followed immediately by another grain delivery, a variable-interval 60s (VI 60s) schedule. To show that the observed response rate increase was due to the contingency rather than just the presentation of grain, Catania and Keller yoked the subjects to a response-independent schedule where the same number of grain presentations at approximately the same intervals occurred. Figure 1 shows the type of result which might be obtained: a higher rate of key pecking with the response-dependent VI schedule than with the response-independent procedure. This difference in response frequency must be due to the contingency, since no other property of the situation was changed (i.e., the amount and the rate of grain deliveries were the same across schedules).

FIGURE 1

Illustration of how rates of responding tend to differ between a response-dependent and a response-independent schedule of food presentation.

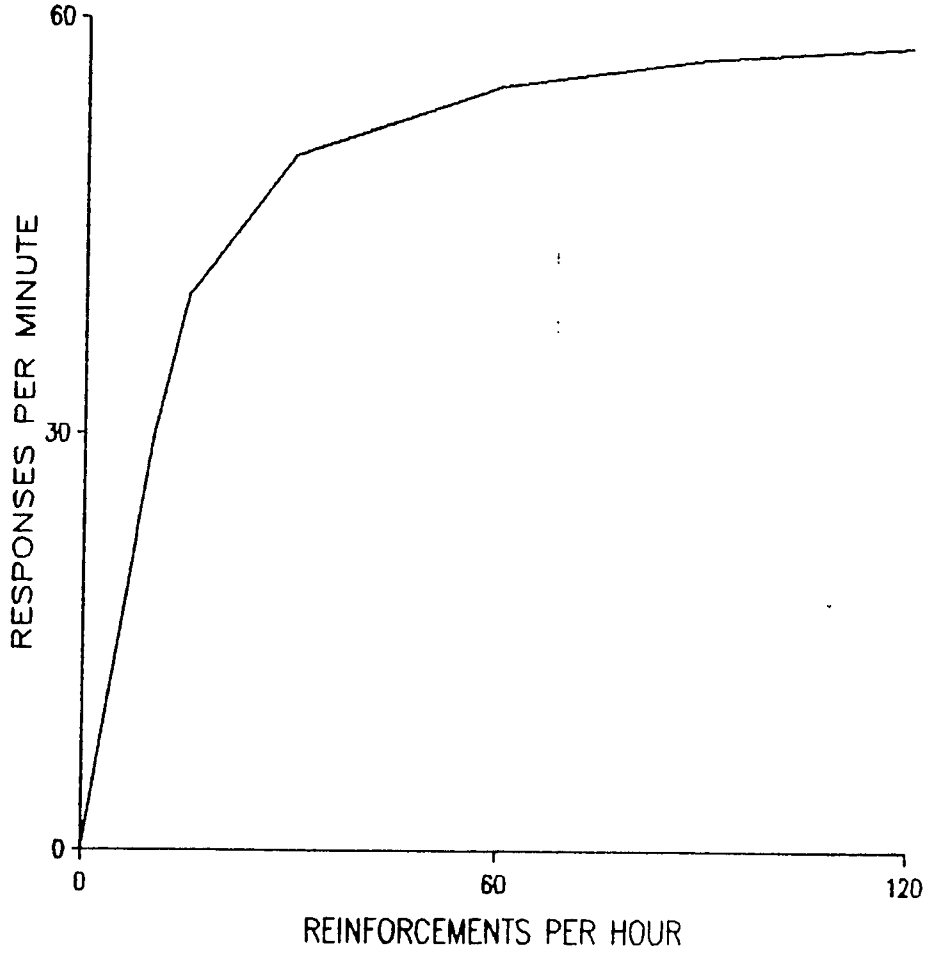


Catania and Reynolds (1968) found that when more response-food contiguities were scheduled per hour (that is, the absolute value of the VI was decreased), a higher rate of key pecking occurred per hour. This trend is exemplified in Figure 2. To appreciate the effectiveness of response-reinforcer contiguity as opposed to the effects of non-contingent environmental changes, compare the changes in response rates of Figure 1 with Figure 2. While the difference in response rates in Figure 1 is due to a change in the contingency (consistent, close, temporal contiguity as opposed to random pairings of responses and reinforcers), the difference in response rates attributed to different reinforcement rates in Figure 2 is NOT due to a change in the contingency defined in terms of peck-reinforcer contiguity. In the case of Figure 2 when the VI value was increased, there was no difference in the degree of contiguity between a food delivery and the peck that produced it, since it was still true that grain delivery had to be preceeded by a key peck.

If contiguity between responses and food affects response rate, then the response rate difference seen in Figure 2 must be due to some other property of reinforcement. In this example, the response rate difference could be due to a difference in the number of occurrences of the contingency within that time span. More

FIGURE 2

Illustration of how rates of responding tend to vary as a function of rate of reinforcement produced by different VI schedules.



specifically, there were more key-peck-food pairings per hour with a VI 20s schedule than with a VI 120s schedule. Since more of these contingencies were experienced per hour, total strengthening effect and thus the frequency of key pecking would be expected to be higher. According to contiguity-based accounts, it is the number of pairings per time (and the number of emitted key pecks which were not followed by food), rather than any difference in the actual contingency, that produced the Catania and Reynolds' response rate increases.

MOLAR RESPONSE DEPENDENCIES

But is contiguity between responses and reinforcers the only component which can be effective in contingency-controlled behavior? Consider the following. A pigeon is presented with grain after approximately every 35 key pecks (a variable-ratio 35 schedule, or VR 35). For a second pigeon grain is available after a single peck but only at the same time grain is made available to the pigeon on the VR schedule (a VI yoked to the VR). Response-reinforcer contiguity is the same on both schedules, and, because foods on the VI schedule are yoked to those on the VR schedule, the same number of response-food pairings per time occur on both schedules. Still, response rate on the VR schedule is much higher than the response rate on the VI schedule (Ferster and Skinner, 1957). This response rate difference can be very cumbersome (although not impossible) to explain when maintaining the position that the only operative contingency is contiguity between key pecks and food. (One possibility, differential reinforcement of interresponse times, is discussed later.) However, if the VR establishes a contingency different from that of the VI, it would not be surprising that the schedules resulted in different response rates.

It has long been noticed (at least since Ferster and Skinner, 1957), that high response rates on a ratio schedule result in higher rates of reinforcement than do lower response rates. It would follow that if response rate were a shapable dimension of responding, and assuming that higher rates of reinforcement are more reinforcing, that of several emitted response rates and several respective reinforcement rates, the higher key-peck rate should be shaped by the ratio contingency. However, with the VI schedule, rate of reinforcement is relatively independent of response rate unless the average interresponse time is long enough to begin approaching the average interfood time. That is, at any particular schedule value, higher response rates may increase reinforcement rate only minimally. (For a more detailed discussion of the quantitative relations between reinforcement rate and response rate see Nevin and Baum, 1980). This is especially true as the absolute schedule value increases. If key pecking requires effort, then small increases in reinforcement rate may not be substantial enough to compensate for the cost of responding. On the ratio schedule, the increase in reinforcement rate is much higher for response rate increases, and the value of the higher reinforcement rate may more than offset the added response cost. The yoked VI schedule does not, to the same degree, differentially reinforce high response rates and therefore should not select a response rate equal to that on the ratio schedule. If this molar dependency between rate of responding and rate of reinforcement were an effective contingency, then it should produce a higher response rate on ratio schedules and a lower rate on interval schedules. Baum (1973) stated the difference between the contiguity and molar dependency account precisely.

> According to the contiguity-based law of effect, an organism's behavior consists of a sequence of the various responses that the organism can make. Since the responses are discrete and distinguishable from one another, the most direct method for assessing the composition of this sequence over any particular period of time (e.g. an experimental session) is to count the number of instances of each response under study.
>
> For the requirement of response-reinforcer contiguity, it is sensible even necessary, to assume discrete momentary responses. When we recognize that responding enters into a more molar relation with reinforcement, that contiguity is not essential, the need for assuming discrete responses disappears. The

> notion of correlation and the description of instrumental behavior as part of a feedback system require instead that we characterize both behavior (output) and consequences (reinforcement, punishment, and response cost: feedback) on a more molar level, trancending the momentary. As noted earlier, the concept of continuous exchange between organism and environment implies measurement that extends over time. (pp 147-148)

CONTROL OF RESPONSE RATE

It is necessary to emphasis one important difference between the molecular-contiguity contingency and the molar-dependency contingency. From the contiguity perspective, the higher the rate of reinforcement the more response-reinforcer pairings, and thus the higher the rate of responding. If contiguity were the only operative contingency, then it should be true that, all other factors being equal, the higher the rate of reinforcement, the higher the rate of responding. From the molar-dependency account, however, rate of reinforcement is an important variable because the highest obtained rate of reinforcement is a selective factor for the response rate (or response distribution) which produced it. That is, independent of the absolute response rate, whichever response rate produces the highest reinforcement rate will be the response rate emitted again in the future.

Many schedules, although defined in terms of the occurrences of discrete key pecks, produce a positive correlation between rate of responding and rate of reinforcement-- as responding increases, so does the frequency of reinforcement. Whether rate is shapable or not, the prediction would be the same; response rate should increase due either directly to this molar dependency or due to the increased number of experienced pairings between key pecks and grain deliveries. It is, then, difficult to determine which contingency is producing the response rate increase. To unconfound the effects of a contiguous from a molar-dependency contingency, these contingencies would have to be arranged so that they would produce opposite effects on response rate. The best way to do this is to keep close temporal contiguity between key pecking and food delivery but vary the dependency between overall response rates and reinforcement rates. (This is the best way due to the possibility that altering the contiguity between responses and reinforcement may also affect the correlation between response rates and reinforcement rates within a circumscribed sampling period-- see Baum, 1973, and the Discussion section of this paper). With a negative-correlation schedule (where rate of reinforcement decreases when rate of responding increases but where food is delivered immediately following the key peck which fulfills the schedule requirement), there would be divergent predictions depending on the operational response unit. If the effective contingency is the associated temporal pairing of a discrete response (a key peck) and the subsequent discrete reinforcer (a food delivery), then a contingency between rate of responding and rate of reinforcement should be irrelevant. When each of 40 foods is delivered individually after each of 40 key pecks within one hour, it should not matter if the scheduled contingency resulted in a positive or a negative correlation between response rate and reinforcement rate, and it should not matter that more foods could be obtained if response rate were lower. However, if response rate is shaped by the molar dependency between rate of responding and rate of reinforcement, response rate should be lower with a negative contingency than with a positive contingency. This is true given the assumption that the organism emits a range of response rates and that the correlated rate of reinforcement effectively selects the response rate that produced it. This should be true, in general, regardless of how frequent or immediate the key peck-reinforcer pairings are.

Perhaps the most obvious way to demonstrate sensitivity to a molar dependency while maintaining a key peck requirement is to reinforce only low response rates. A contingency can be presented where x seconds have to elapse between key pecks in order for food to be delivered. If response rate decreases, then it would be consistent to say that response rate is controlled by the higher rate of reinforcement for that pattern. If response rate does not decrease, the molar dependency must not be effective for controlling behavior. On schedules which differentially reinforce low rates of behavior (DRL schedules), key-peck rate does decrease as the contingency requires lower rates (Blough, 1963; Kelleher, Fry, and Cook, 1959; Mallott and Cumming, 1964; and Shimp, 1968). Although DRL schedules do not produce uniform low rates but instead frequently show bursts of higher response rates, the molar dependency between response and reinforcement rates could be effective.

This decrease in key-peck rate during the DRL schedule, however, is not inexplicable by an account which does not accept rate as a shapable response dimension, even though no decrease would have been more amiable for the view. It is plausable that the time between responses is differentially associated with reinforcement so that some times are associated with reinforcement and some times are not. A short time since the last response on the DRL schedule is a temporal situation in which food never occurs. This would be no different from saying that blue key pecks are reinforced and red key pecks are not. Contiguity of responses and reinforcement during longer IRTs (a discriminable stimulus situation) might produce lower response rates. The DRL schedule has been used to show sensitivity to the correlation between rates, but either the contiguity or the molar-dependency contingency could produce the observed decrease in response rates during DRL schedules. Although the logic behind such schedules is sound, the dynamics of the schedule prevent a satisfactory interpretation of the results.

Vaughan and Miller (1984) devised a negative-contingency schedule which can be used to investigate the possiblity that rate of responding is directly shaped by the molar dependency. The core of the schedule is a linear VI schedule, which differs from the more traditional VI schedules in the way reinforcement opportunities are accumulated. In the typical VI schedule once a reinforcer is available, it is held until obtained, and no other reinforcers become available. If, for whatever reason, response rate decreases on the traditional VI schedule, an uncollected reinforcer will hold up the availability of other reinforcers and the obtained rate of reinforcement will decrease below the potential rate of reinforcement. It is this aspect of the schedule which produces a positive correlation between response and reinforcement rates, thus establishing a molar dependency. On the linear VI schedule, an available reinforcer is held until a key peck is emitted and reinforcement is collected, but the VI schedule proceeds and all additional reinforcers are stored to be collected whenever responses occur. It is possible that after a period of low responding on the linear VI schedule so many reinforcers have been stored, that for a period of time every key peck produces food delivery. Because each interval does not stop and reinforcers cannot be missed (unless response rate is extremely low and the session ends before all stored reinforcers are collected), overall reinforcement rate is independent of overall response rate.

In the Vaughan and Miller procedure, superimposed on this linear VI was a negative contingency in which a certain number of responses cancelled one of the stored reinforcers. If no reinforcers were stored, that number of responses would cancel a future reinforcer. Thus, the higher the response rate, the lower the rate of reinforcement. For example, with a linear VI 60s schedule, the highest obtainable rate of reinforcement would be 60 foods per hour. Given a subtractive FR 30 schedule, a response rate of 30 key pecks per minute would, on the average, cancel all foods (resulting in 0 foods per hour); a response rate of 15 key pecks per minute would, on the average, cancel half the foods (resulting in 30 foods per hour); while a response rate of 5 key pecks per minute would, on the average, cancel 1/6 of the foods (resulting in 50 foods per hour). If overall rate of food is important in the molar contingency, then overall key-peck rate should be lower when the subtractive FR is operative. Moreover, making the subtractive FR requirement smaller should further decrease response rates. Higher rates of reinforcement would be obtained if the subject responded at a lower rate. (In the Vaughan and Miller procedure the optimal resonse rate was about 2 responses per min, but the exact optimal response rate would depend on the actual schedule values). If each reinforcer strengthens just the discrete response before it, then the response rate should not be lower on this schedule than on either a positive or zero correlation schedule with the same rate of peck-food contingent pairings.

Vaughan and Miller studied three VI values (VI 30, VI 45, and VI 60) and three FR values (FR 20, FR 40 and FR 60) with this negative-contingency schedule. Of most importance was the observation that the rate of responding for all schedule values was much higher than it should have been had behavior been controlled solely by the molar dependency between response rate and rate of reinforcement. Although about two responses per minute would have resulted in the highest reinforcement rate, between 10 and 60 responses per minute were emitted. Because the response rate was so high, many foods were cancelled, and rate of reinforcement was much lower than the optimal. Vaughan and Miller interpret this as evidence against control by molar dependencies between response and reinforcement rates.

Although the predicted low response rate was not emitted, the possibility of response rate as a reinforceable response dimension cannot be rejected entirely. Typically, as the VI requirement was increased (making a weaker negative correlation between response and reinforcement rates), response rate decreased. This decrease in response rate is consistent with either a response-rate shaping view or a discrete-response strengthening view since the obtained rate of response-reinforcer pairings and the correlation between response and reinforcer rates decreased. Their results also showed that as the FR size was increased, response rate increased. This is consistent with the contiguity account, since these conditions also had a higher frequency of response-reinforcer pairings. However, it is also true that as more key pecks were required to cancel reinforcement, the weaker would be the negative contingency between response rate and reinforcement rate. Thus it is possible that the molar dependency could have exerted control but that the contingency was so weak that subjects really did not come into contact with it. So, again, both behavioral accounts can interpret the change in behavior.

Catania reminds us that the way to show that a proposed contingency is having an effect is to present the contingency, note the behavioral change, then alter just the contingency and watch for behavior to change. Although the maximal response rate was not observed in the Vaughan and Miller study, their results are not completely uninterpretable by an appeal to the molar dependency between response and reinforcement rates. By removing the molar dependency, however, response rates should change only if the molar dependency had been responsible for observed response rate. That is, if response rate is but an index of the effectiveness of a molecular contingency, then a subject obtaining the same number of response-reinforcer pairings per session but without the negative contingency should emit the same response rate. However, if the contingency between rate of responding and rate of reinforcement is an effective one, its removal should alter response rate. A higher response rate on a schedule yoked to the negative-correlation schedule (response-dependent food presentations at the same rate but without the negative correlation between overall response rate and reinforcement rate), would be consistent with control by a molar-dependency contingency, but inconsistent with control by contiguity.

Vaughan (1982) presents the results of yoking overall reinforcement rate of a linear VI to the rate of reinforcement from the negative-contingency schedule. From his Figure 12-8, it can be seen that out of the 26 yoked conditions, 15 conditions showed a higher response rate when the negative contingency was removed, 6 conditions showed a higher response rate on the negative contingency schedule than on the yoked linear VI, and 5 conditions showed no obvious response rate difference between conditions. Thus, over half the conditions did demonstrate what could be interpreted as some sensitivity to the negative contingency, and this effect was statistically reliable. These effects, however, were not always consistent and seemed fairly weak in many cases.

Vaughan (1983) proposed that the increase in response rates observed when yoked response-dependent schedules without the negative contingency were presented was due not to the effectiveness of the negative contingency, but, as with the DRL schedule, to molecular inhomogeneities which produced differential reinforcement of IRTs. Specifically, on the linear VI schedule without the negative contingency all IRTs have an equiprobable chance of being reinforced if the reinforcement storage counter is above 0, since any key peck will be reinforced. If the counter is at 0, then the probability of reinforcement increases as IRT duration approaches the length of the longest scheduled interfood interval, the same as the probabilities on the typical VI schedule. When the negative correlation between response and reinforcement rates is added to the linear VI schedule, conditions are set for the differential reinforcement of long IRTs. Consider what happens at a molecular level. If the reinforcement storage counter is above or at 0, then the probability of reinforcement is the same as on the linear VI schedule without the negative contingency. However, when many key responses have occurred and the storage counter is below 0, then the shortest time to food is two intervals away if one food has been subtracted, three intervals away if two foods have been subtracted, etc. This property of the schedule should differentially reinforce even longer IRTs than the typical VI schedule of the same value. As Vaughan found, with the same rate of food but without the negative contingency (i.e., the storage counter was never below 0), response rates were higher than when the negative correlation was present. Similarly, the differential reinforcement of IRTs analysis can also explain the response rate changes seen in the Vaughan and Miller results without an appeal to the molar-dependency contingency. Thus, neither the Vaughan and Miller nor the Vaughan yoked-control studies offer unequivocal evidence in support of one or the other contingency.

As mentioned previously, Skinner did recognize the molar dependency between rate of responding and rate of reinforcement which was produced by many schedules. He did not, however, view this as a determining factor in behavior control. For Skinner, the effective contingency was molecular; reinforcement strengthened the discrete response which it followed. However, several people (Baum, 1973; and Rachlin, Battalio, Kagel, and Green, 1981) argued that the molar dependency was actually the effective contingency. That is, the highest obtained rate of reinforcement is a selective factor for the response rate (or distribution) which produced it.

Vaughan and Miller were not specifically looking for the effectiveness of a negative correlation. They were testing a reinforcement maximizing hypothesis, and they took as their behavioral comparison an ideal rate of behavior based on absolute control by the negative correlation where rate of reinforcement would be maximized. The observed response rate on the Vaughan and Miller negative-correlation schedule could not, obviously, be due to just the effects of a negative contingency, since Vaughan and Miller's subjects did not show the optimal decrease in response rate. But, since Vaughan has shown that the negative correlation might exert some control, and since the response rate changes in the Vaughan and Miller study are consistent with at least partial control by the molar dependency, the possibility remains that more than one contingency can affect response rate. If contingencies produce conflicting levels of key pecking, the observed rate of responding could be a joint product of different contingencies operating at different levels with different response units.

A molar dependency between response rate and reinforcement rate and contiguity between responses and reinforcers are both present in most schedules. However, it is often assumed that only one of the contingencies can be effective in behavioral control. By making these opposing contingencies, the observed direction of response rate change would be conclusive evidence as to which contingency was effective, if it were true that only one of the contingencies is effective at a time. An alternative view, however, has been expressed by Catania and Keller.

> We may argue that organisms are sensitive to those features of the environment that are correlated with the presence or absence of response-reinforcer contingencies....By themselves, contiguities are inadequate. If local asynchronies between responses and consequences could not be tolerated in contingencies, only automated environments would be capable of maintaining behavior. Instead, organisms must be able somehow to integrate events over time and respond on the basis of correlations among reinforcement rates and response rates. But they must also make contact with other simpler schedule dimensions correlated with contingencies. (Catania and Keller, p 162)

Perhaps there is no one 'primary' contingency. Instead, there may be levels of control determined by the contingencies at hand. Different schedule arrangements may produce many different contingency properties.

> Contingency features, then, are those features of reinforcement schedules that provide the basis for differential control by response-dependent and response-independent reinforcers....Some of these features will be more likely to be present in some contexts than in others. Thus, it is unlikely that any one alone will be either a necessary or a sufficient feature to control differential responding. (Catania and Keller, p 163)

Along those lines, in a schedule where there is a weak contingency between overall response and overall reinforcement rates but close temporal contiguity between responses and reinforcers, response rate may be influenced relatively more through this molecular contiguity than through the molar contingency. A schedule which produces a strong negative correlation between overall response and reinforcement rates but where the reinforcer is randomly delayed from the response may influence response rate relatively more by the molar-dependency contingency than by response-reinforcer contiguity. Schedules which produce both a strong negative correlation between response and reinforcement rates and close temporal contiguity between responses and reinforcers should produce a moderate response rate, given no other factors which may alter the effectiveness of the two contingencies. It may be that, functionally, the Vaughan and Miller schedule is like a concurrent schedule where one contingency acts to increase response rate and the other to decrease response rate. What is needed, then, is to separate the independent contributions of the contingencies.

The problem is to empirically separate the differential effects of the molecular and molar contingencies within a procedure which does not differentially reinforce long IRTs only when the negative contigency is presented. Perhaps the way out of this dilemma is to present the linear VI and the linear VI with the subtractive FR schedules concurrently on two keys. Responses on only one key (the linear VI with the subtractive FR component) would subtract a potential food delivery, but it would be subtracted from the total number of reinforcements. Therefore, the reinforcement storage counter could be below 0 for the schedule without the negative contingency. At a molecular level, this should lead to differential reinforcement of long IRTs on both keys where the probability of reinforcement for specific IRT durations should be equal across keys. If IRT reinforcement were the influencing factor, there should be equal response rates on both keys as long as the same number of response-food pairings occurred on both keys. At a molar level, however, the distribution of responses across keys will affect the overall rate of reinforcement. The more responses which are emitted to the subtractive FR key, the lower the overall rate of food. This dependency should produce a shift in the response distribution away from the negative contingency key. Specifically, the highest rate of reinforcement would occur when the response rate on the negative-contingency key was low.

Differential reinforcement of IRTs would produce results which, in some ways, mimic the results which would be expected if the negative correlation were an effective contingency. This would be true, however, only when the negative-correlation and zero-correlation schedules were presented in successive sessions. While the molar properties of the schedules with and without the negative contingency are different independent of when the schedules are presented, the local properties of the contingencies are different when the schedules are presented concurrently or successively.

In the present study the local properties of the zero- and negative-correlational contingencies will be similar, while the molar properties of these contingencies will be different. A linear VI schedule will be programed so that half the time food reinforcement will be available for a peck on the right key, and the other half of the time food reinforcement will be available for a peck on the left key.

No matter what the overall rate of food, reinforcement is delivered equally often for both keys, ensuring the same relative frequency of foods and the same minimal delays between the key pecks completing the schedule requirement and food delivery on both keys. In this respect the molecular contingency between key pecks and reinforcement should be the same on both keys. If the schedule has assigned reinforcement to the right key, a right-key peck must be emitted to collect the food. The same for the left key. If the schedule has assigned a reinforcement and an appropriate key peck is not made, that reinforcement is held until the key peck is made, but the VI schedule continues to progress and food availability is stored. The negative contingency will then be added for pecks on the left key only, although both keys will remain available at all times. Every x number of left-key pecks decreases the potential overall food rate by subtracting a count from reinforcement storage. The more left-key responses emitted at any time in the session, the more reinforcements are cancelled. Thus, the overall absolute rate of reinforcement decreases as the left-key response rate increases, but the relative rate of reinforcement remains at .50 regardless of response rates on the two keys. Keeping the relative rate of reinforcement at .50 is important because the intent will be to see if the negative contingency between left-key pecks and overall (both keys) reinforcement rate will cause pecks to differentially decrease on the left key. If such a shift in relative response rates occurs, it will be important to exclude a shift in the relative reinforcement rates as a factor.

The proposed concurrent schedule seems an appropriate test of the effectiveness of the molar dependency for at least two reasons. First, as already mentioned, by presenting the negative contingency concurrently with a schedule with no negative contingency, the possibility of molecular stimulus inhomogeneities across the schedules is controlled for. Second, the molar-dependency contingency was originally proposed in context of the concurrent schedule (Baum, 1973; and Rachlin, Green, Kagel, and Battalio, 1976). The typical concurrent situation studied was one where both VI schedules resulted in a positive correlation between overall response rates and reinforcement rates. With this conc VI VI schedule the relative rate of responding usually matched the relative rate of reinforcement. Such behavior would not be unexpected if reinforcement strenghened the preceeding response, since rate of responding should be proportional to the number of pairings. Rachlin, Green, Kagel, and Battalio (1976) have shown that on many conc VI VI schedules the distribution of responding between alternatives which maximizes total rate of food is this matching point. If subjects were maximizing, then responses would be distributed between the alternatives in proportion to to relative rate of reinforcement even though it was the molar distribution of responses that was reinforced and not the individual responses which were strengthened. If control by the molar contingency is shown to be an effective contingency in the present study, then the molar dependency account gains credibility as an explanation for conc VI VI schedule performance.

In summary, the question to be addressed is whether a contingency between rate of responding and rate of reinforcement can directly shape response rate when both the molar dependency and peck-reinforcer contiguity are present. Vaughan and Miller's and Vaughan's results were consistent with partial control by the negative contingency when response rates with and without the negative contingency were compared. Those results, however, were not robust and are open to interpretation from a singular, molecular-contingency account. By presenting contrasting contingencies (contiguity on one key and contiguity with a negative contingency on the other key), it may be possible to heighten the effects of the negative contingency and compare response rates across keys. Instead of looking for absolute control of the rate of responding by the molar dependency, it may be more appropriate to look for partial control by the negative contingency and try to identify what variables influence relative contingent control. Since the same number of response-food pairings will occur on both keys, and since IRT duration should be differentially reinforced to the same extent on both keys, there should be no molecular reason why response rates would differ between the keys. If it can be shown that response rate distributions shift away from the negative-contingency key when the molar dependency is present, then there is evidence that response rate is a shapable response dimension. When response rate can be directly shaped as a unit, response rate will not be an accurate index of the response strength due to the contiguous relationship between individual responses and reinforcers. The procedure of using a second key is thought likely to optimize conditions for observing an effect of the molar-dependency contingency if such a contingency is, indeed, effective.

CHAPTER II

METHOD

SUBJECTS

Six experimentally experienced pigeons (five White Carneaux and one Silver King) were deprived to about 80% of their free-feeding weights. When not in the experimental chamber, subjects were individually housed in home cages where water and grit were freely available. One subject (76) died after completion of baseline recovery sessions during Phase I. Subject 5189 was substituted.

APPARATUS

A standard Lehigh Valley two-key experimental chamber 31 cm x 34.5 cm x 35 cm was used. In the box two Plexiglas response keys were mounted on the intelligence panel 25 cm from the floor and 4 cm apart, center to center. A response on either key provided an audible feedback click from a relay mounted behind the panel. During the sessions, both keys were illuminated from behind by green light at all times except during hopper presentation. The hopper opening was equidistant between the keys but 10 cm below them. The hopper was illuminated during each 3 sec presentation. In the upper right corner of the intellegence panel was a single houselight, illuminated during the entire session, except during hopper presentations. A response on either key provided an audible feedback click from a relay mounted behind the panel. A fan provided ventilation and masking noise. All electromechanical relay equipment for programming and data recording were located in a room adjacent to the experimental room.

During some conditions a physical barrier was mounted between the keys (hereafter, conditions with no barrier will be referred to as Phase I and conditions when the barrier was in place will be referred to as Phase II). A clear Plexiglas square, 7 cm by 7 cm and .5 cm wide, was mounted equidistant between the keys. The bottom of the barrier was 8 cm above the hopper and the top of the barrier was 5 cm from the ceiling. It was possible to observe both illuminated keys from any point in the chamber.

PROCEDURE

Each session consisted of 40 obtained hopper presentations or 40 minutes, whichever came first. Each condition was run until there were no consistent trends in response rates for five consecutive sessions, with the additional stipulation that at least 15 sessions were run per condition. Sessions were run once per day, 7 days a week. The order and number of sessions for all subjects during all conditions are shown in Table 1.

Baseline. Since all subjects were experimentally experienced, preliminary hopper training and key-peck shaping were not necessary. The baseline condition consisted of linear VI schedules (either VI 30s, 45s, or 60s). Each set of two subjects was presented with a different value of one of the VI schedules throughout the baseline and experimental sessions. A single Fleschler and Hoffman (1962) VI schedule tape was used. This type of programming generates a VI schedule where the probability of reinforcement in any particular brief interval of time is a constant function of the time since reinforcement. When the VI timer set up the opportunity for reinforcement, a 5-digit 'storage counter' was incremented by one. If the counter was above 0, then an appropriate key response produced grain delivery. The VI tape did not stop when reinforcement became available, but proceeded and could set up and store additional reinforcement opportunities. A 12-position stepper was used to determine which key (left or right) reinforcement was available on. The stepper was programmed to quasi-randomly select one of the two keys. Each time the hopper was presented, the storage counter was decremented by one, and the stepper was operated to the next position. Since the stepper was operated to the next position at the

TABLE 1

Order of conditions and number of sessions for each subject (Ss) during all conditions. Conditions designated -L indicate contingency operative on the left key; -R indicates contingency operative on the right key; -H indicates the 2-second hold was operative.

Ss	VI	Condition	Sessions	Ss	VI	Condition	Sessions
76	30	Baseline	80	1125	30	Baseline	45 (1)
	30	FR 20 -L	24		30	FR 60 -L	24
	30	FR 20 -L	82 (2)		30	FR 5 -L	55
	30	Baseline	9 (3)		30	Baseline	15
5189	30	Baseline	15 (B)		30	Baseline	22 (B)
	30	FR 20 -L	17 (B)		30	FR 10 -L	16 (B)
	30	FR 20 -R	20 (B)		30	FR 10 -R	20 (B)
	30	Delay -R	27 (B)		30	Delay -R	27 (B)
	30	Delay -L	15 (B)		30	Delay -L	15 (B)
	30	Baseline -H	25 (B)		30	Baseline -H	24 (B)
4155	45	Baseline	42 (4)	2690	45	Baseline	83 (5)
	45	FR 20 -L	24		45	FR 60 -L	24
	45	FR 20 -L	79 (2)		45	FR 5 -L	56
	45	Baseline	15		45	Baseline	15
	45	Baseline	22 (B)		45	Baseline	22 (B)
	45	FR 20 -L	15 (B)		45	FR 10 -L	16 (B)
	45	FR 20 -R	20 (B)		45	FR 10 -R	20 (B)
	45	Delay -R	27 (B)		45	Delay -R	27 (B)
	45	Delay -L	15 (B)		45	Delay -L	15 (B)
	45	Baseline -H	24 (B)		45	Baseline -H	24 (B)
6861	60	Baseline	46	1346	60	Baseline	83
	60	FR 20 -L	23		60	FR 60 -L	24
	60	FR 20 -L	75 (2)		60	FR 5 -L	54
	60	Baseline	12		60	Baseline	14
	60	Baseline	18 (B)		60	Baseline	21 (B)
	60	FR 20 -L	16 (B)		60	FR 10 -L	15 (B)
	60	FR 20 -R	20 (B)		60	FR 10 -R	20 (B)
	60	Delay -R	26 (B)		60	Delay -R	26 (B)
	60	Delay -L	14 (B)		60	Delay -L	14 (B)
	60	Baseline -H	21 (B)		60	Baseline -H	23 (B)

(1)Subject 1125 also experienced 9 sessions at VI 45s.
(2)Cumulative number of sessions at FR 20.
(3)Subject 76 died during Baseline recovery.
(4)Subject 4155 was exposed to 3 sessions at VI 30s.
(5)Subject 2690 also experienced 7 sessions at VI 3m.
(B)Conditions with the barrier in place.

end of food delivery, once a side key was designated, only that particular topography resulted in food. This ensured relatively equal food deliveries for each key. Note that since one VI tape assigned foods to both keys, the scheduled concurrent VI values per key were actually twice the overall tape value (i.e., a VI 30s tape resulted in a VI 60s schedule on each of the keys).

Subtractive FR. During the experimental conditions the concurrent VI schedules operated exactly as during baseline, except that the negative contingency was added to the contingency on the left key. With this contingency every Nth left-key peck (60, 20, 10, or 5) decremented the storage counter by one, regardless of key assignment. If the storage counter was below 0 and the VI elapsed, the counter was incremented by one but the hopper was not available. One subject from each of the three VI values was presented with the subtractive FR 20, while the other subject at that VI value was presented with either the subtractive FR 60, FR 10, or FR 5 schedule. In an attempt to amplify the difference between the contingencies on the two keys, those subjects that experienced the FR 60 schedule were switched to a subtractive FR 5 schedule. This FR schedule tended to decrease rate of reinforcement so much that during some sessions food was never obtained. Therefore, these subjects were presented with a subtractive FR 10 schedule. The FR 20 subjects remained on that schedule to probe the effects of continued exposure to the contingency.

Determination of the first four conditions (Phase I), showed a continued high response rate on the left key when the negative-contingency schedule was present on that key. A measure of responses made on a particular key before switching to the other key showed that subjects typically made only about 2 responses per key before switching. From a molecular, contiguity viewpoint, this could set conditions for strenghtening of left-key responses by delayed right-key reinforcements. Even if the molar dependency were partially effective, right-key foods which closely followed left-key responses might strengthen the discrete left-key pecks enough to obscure the effects of the molar dependency. Additionally, even though the molar dependency is between the overall distribution of responses and reinforcement rate, the individual key pecks must be discriminable if the contingency is to be effective. When right and left pecks can occur closely in time, they may not be differentiable. Therefore, a changeover delay (COD) was needed which would temporally isolate the key responses.

The most common COD used is a temporal COD where food is not delivered until several seconds after a changeover (CO). However, in the present study, a physical barrier was placed between the keys so that rapid switching could not occur (Baum, 1982a). The temporal COD was not used here for two reasons. First, this sort of COD could produce discriminable temporal stimuli associated with no food (as in DRL schedules) which could alter the effectiveness of the contingencies. The physical barrier temporally separates responses between the keys, but does not produce a period where foods cannot be obtained within either component. Second, the temporal COD tends to produce bursts of responses immediately following a CO which would force overall reinforcement rates down. During Phase II the effects of the negative contingency were studied when the physical barrier separated left-key and right-key responding. The negative contingency was presented on the left and on the right key to see what extent differential key responding (or the lack of) was due to a key bias.

Delayed reinforcement. Since response rates remained fairly stable during all previous conditions, it is imperative to show that some manipulation can affect a response rate change in this procedure. For this reason, a delay was imposed on the right key, where food was not delivered until 2 sec after the right-key response which fulfilled the VI requirement. This delay was timed from the first right-key response after food had become available for the right key, and the delay was not affected by any responses within that 2 sec delay time (i.e. the 2 sec timer was not reset for any reason). This type of delay could alter the schedule in at least two ways, besides separating right-key responses from food delivery. First, it increases all right-key interfood intervals by 2 sec. Second, since food never immediately follows a right-key response, CO responses to the right-key are never immediately reinforced. Both of these conditions are absent for left-key responding and could differentially decrease right-key responding independently of the 2 sec delay. Therefore, these conditions were also added to the left key so that any differential decrease in right-key responding should be due only to the effects of temporal contiguity. That is, when food was available for a left-key response, a left-key response initiated a 2 sec timer. When this 2 sec period had timed out, the next left-key response was immediately followed by food delivery. Although additional left-key responses during this 2 sec period did not affect this hold time, a right-key response terminated the hold until the next left-key response was made. Thus, 2 sec were added to interfood times on both keys, the first CO response was never immediately reinforced on either key, reinforcement was response-dependent on both keys, there was no scheduled correlation between response rate and reinforcement rate on either key, but reinforcement was contiguous only with left-key responses. This condition was an attempt to evaluate the relative contribution to rate of responding from the temporal contiguity contingency. The function of the keys were then reversed so that the delay between responses and food delivery occurred on the left key in order to examine the possibility of a key bias.

It is feasible that the 2 second hold time on the non-delay key might increase response rates on this key. If this happens, then the relative frequency measures would confound this increase with any decrease in response rates on the delay key. In order to verify the effects of the 2 second hold time, 24 sessions were run with no delay or negative contingency on the keys but with a 2 second hold time on both keys (baseline with 2 second hold).

CHAPTER III

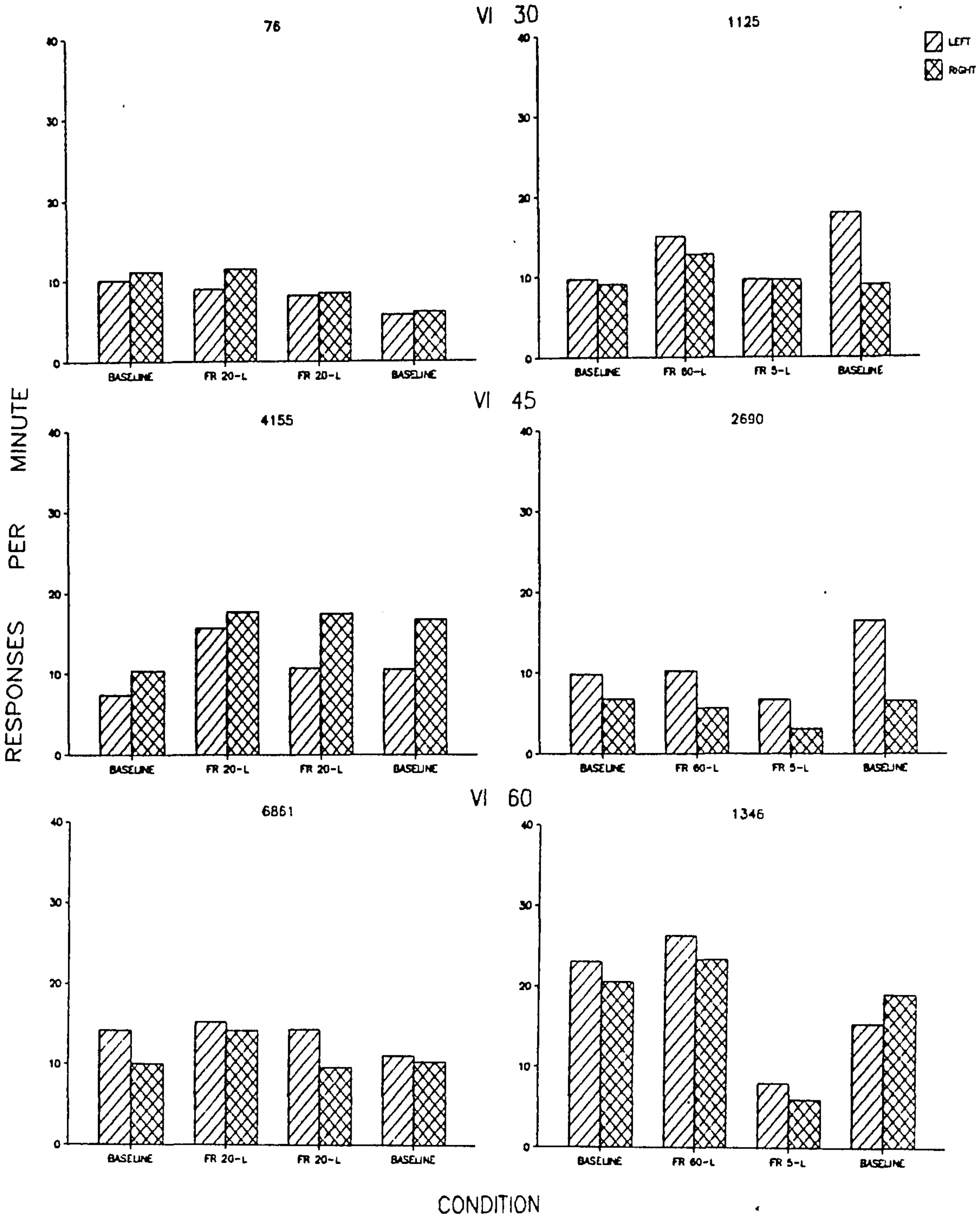
RESULTS

PHASE I

If the molar dependency was an effective contingency, then the rate of left-key responding should have decreased when the contingency was in effect. Furthermore, the lower the FR requirement, the more left-key responding should have decreased since this should have produced a stronger negative contingency between left-key response rate and overall reinforcement rate. Figure 3 shows left- and right-key absolute response rates for all conditions (baselines, FR 20, FR 60, and FR 5) during Phase I. Each panel shows response rates for an individual subject. For each pair of bars within a panel, the left bar shows left-key response rates and the right bar shows right-key response rates. The most striking finding is that response rates between keys were not differentially affected. Although there was some variability in the total absolute response rates, left-key response rates were not systematically reduced.

FIGURE 3

Responses per minute on each key during the last five sessions for each subject in all conditions of Phase I.

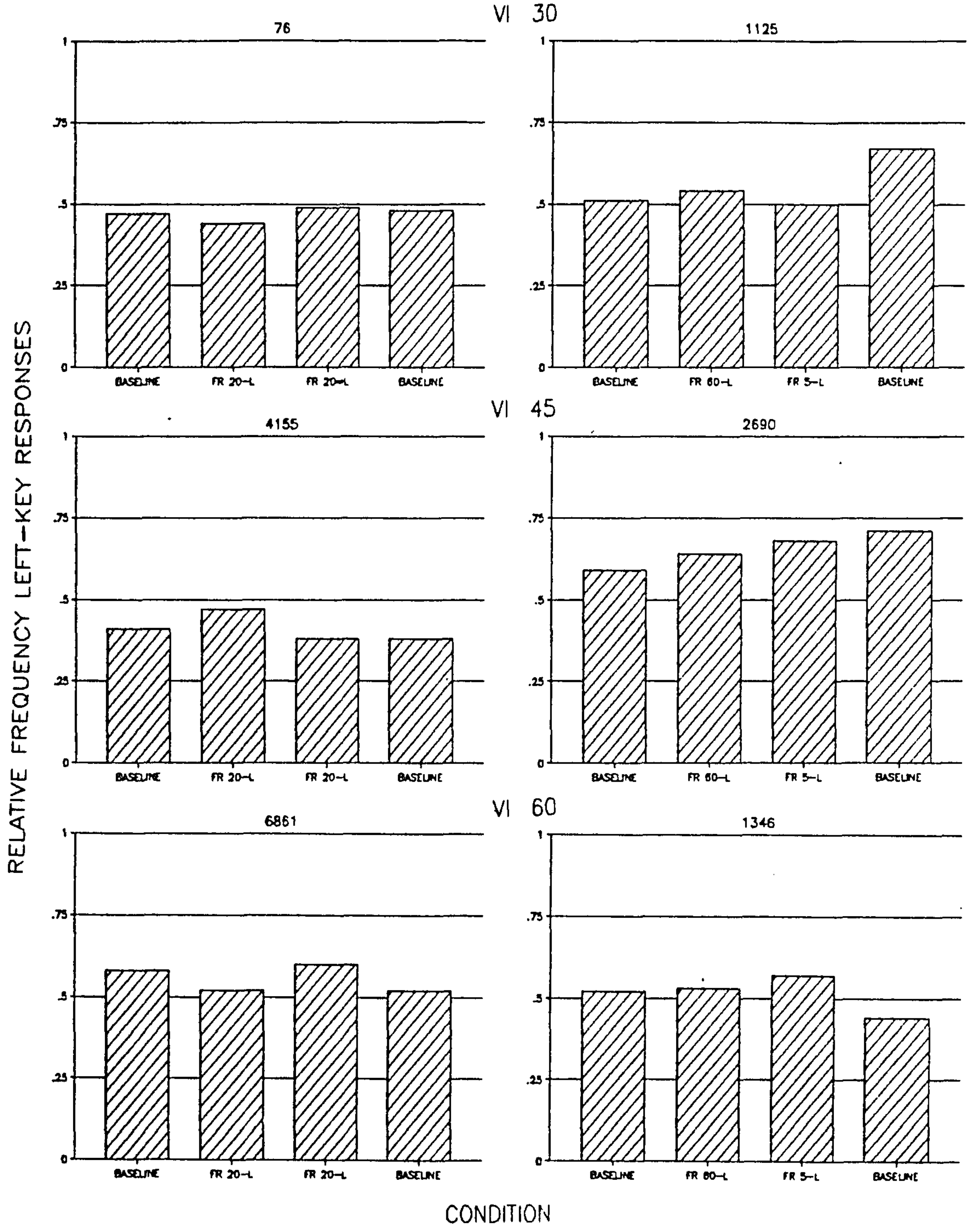


It may be that the negative contingency was affecting left-key responding differently from right-key responding but that such changes are hard to see in the absolute response rate measure. Figure 4 shows the relative frequency of left-key responding for all subjects during Phase I. There seems to be no obvious trend in the left-key response proportions across conditions. For most subjects, relative left-key responding remained close to .50 in all conditions.

Perhaps the molar dependency affected not the absolute or relative rate of left-key responding, but time spent on the left key. The relative frequency of time spent on the left key has been used as a measure of preference (Brownstein and Pliskoff, 1968). Time spent on the left key was measured from the first left-key response after a right-key response to the next right-key response. If less time were spent on the left key, but responses were emitted at a higher rate while on the left key, equal absolute and relative response rates could be obtained. (This higher local left-key response rate would, of course, be contrary to the proposed effects of the molar dependency between response rate and reinforcement rate). As Table 2 shows, the relative amount of time spent on the left key for the second and third conditions of Phase I (subtractive FR 20 or FR 5 and baseline recovery) were very similar. Regardless

FIGURE 4

Relative frequency of left-key responses during the last five sessions for each subject in all conditions of Phase I.



of whether the negative correlation was operative or not, subjects spent about half of the session responding on the left key.

Given that the absolute and relative rates of responding remained at about the same level and the relative time spent on the left key remained at about .50 for these conditions, it was imperative to check the obtained rates of reinforcement to make sure the negative contingency was actually operative. Although the relative rate of reinforcement was constrained at .50, the absolute rates of reinforcement depended on the VI value, the subtractive FR value, and response rates. Figure 5 shows the mean rate of reinforcement averaged between the left and right keys during all conditions of Phase I. The absolute rate of reinforcement did actually decrease when the subtractive FR requirement was presented. Furthermore, there was a graded decrease in reinforcement rates as the FR requirement decreased and as the average interfood interval increased. Both of these effects are in accord with the schedule properties.

In general, Phase I showed little effect of the molar dependency. Overall, response rates were generally unaffected by the addition of either a subtractive FR 20, FR 60, or FR 5 schedule. There was no noticeable differential effect of the experimental manipulations on the relative

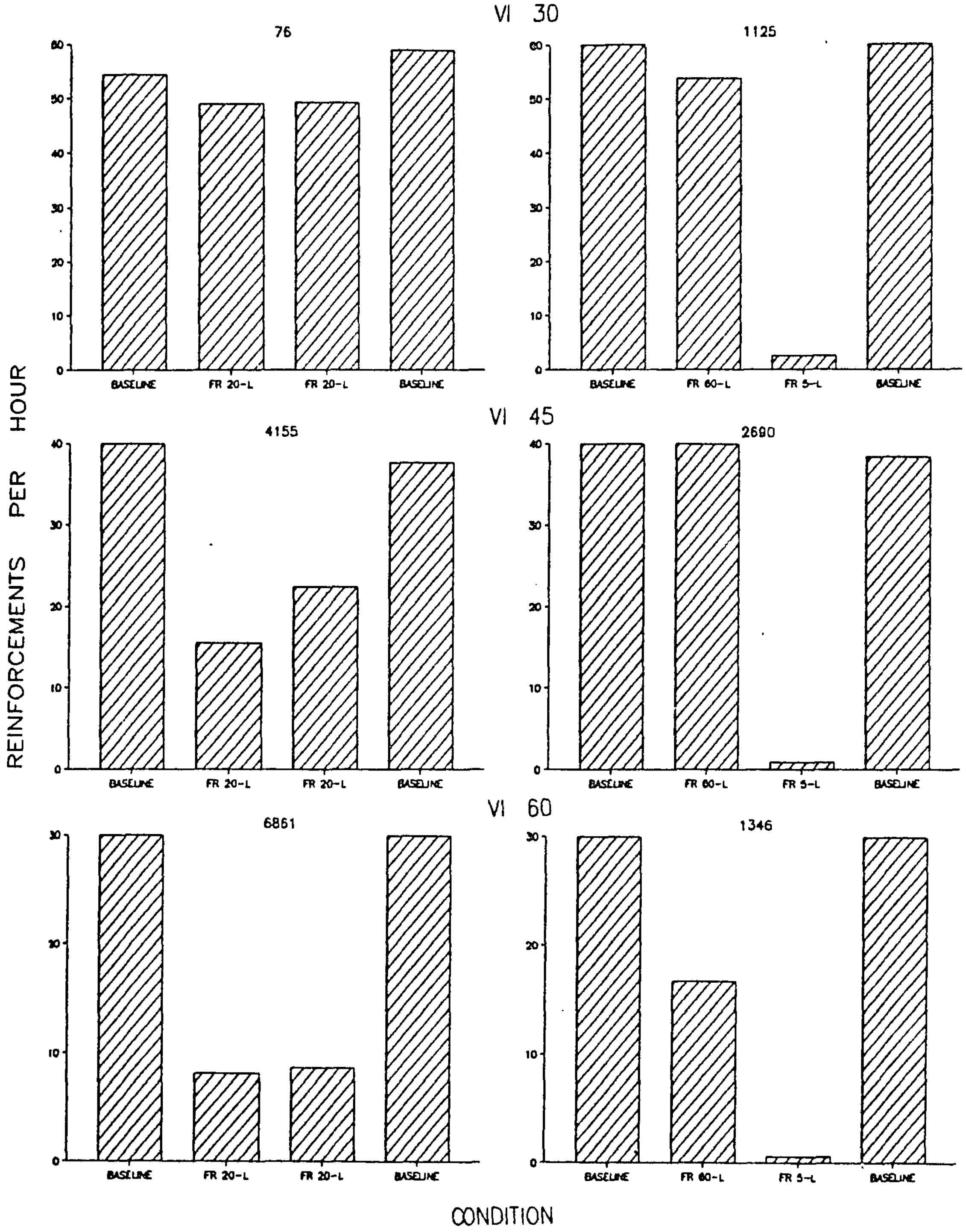
TABLE 2

Relative frequency of time spent on the left key for all subjects during the last five sessions for subtractive FR 20/FR 5 and baseline recovery sessions of Phase I.

	VI 30		VI 45		VI 60		
	FR 20	FR 5	FR 20	FR 5	FR 20	FR 5	
	76	1125	4155	2690	6861	1346	MEAN
FR (left)	.52	.55	.40	.59	.56	.72	.56
BASELINE	.46	.70	.47	.61	.50	.44	.53

FIGURE 5

Average reinforcement rates per key during the last five sessions for each subject in all conditions of Phase I. Rate is shown per key, so the maximum possible is half that provided by the schedule.



frequency of left-key responses. Overall rate of responding was a little lower when the FR 5 was operative, but so was the rate of reinforcement, so it is not clear which factor (the negative contingency or the number of response-food pairings) was responsible. Baseline response rates during redetermination tended to be more similar to original baseline rates for subjects exposed to the FR 20 as opposed to the FR 5 schedule. Again, this may indicate some slight effect of the negative contingency, but with such a small sample size it is difficult to tell.

Discussion of Phase I. There is one possible explanation for no response-rate difference during the negative-contingency procedure. On concurrent schedules subjects alternate responding between the two keys, usually obtaining more foods within the first few responses of a response run on a key than after prolonged responding on that key. This factor can reinforce COs between the keys, or the tendency to switch keys (Pliskoff, 1971). Two lines of evidence suggest that it is important to evaluate more closely this aspect of the schedule. First, during some FR 20 or FR 5 sessions, an unsystematic effort was made to further separate the schedules. That is, during some sessions the overall rate of responding was decreased by adjusting the subjects' deprivation level to about 90% of the free-feeding weight. This increase in weight not only decreased overall response rates, but also tended to decrease the relative frequency of left-key responding. It is possible that this manipulation introduced an 'artificial' COD where, due to the lower response rates, the keys were functionally differentiated. This lower response rate was transient for most subjects. Second, the rate of COs was lower when the subtractive schedule was FR 5 than when it was FR 20 or when there was no FR (i.e., baseline conditions) which would be consistent with the proposition that the subtractive FR 5 schedule did exert some effect on rate of responding. But, even when the subtractive schedule was FR 5, subjects responded only about three times on the left key before switching to the right key. In Phase II a physical barrier was placed between the keys to separate responses on the keys.

Phase II included an attempt to see whether changing the temporal contiguity between responding and reinforcement on one key would influence the response rate on that key. Specifically, during some conditions of Phase II, a 2 second delay was imposed between the effective key responses on one key and food delivery for that key peck. If temporal contiguity between responses and food delivery is important, then there should be differential responding between the keys, with the response rate on the delay key being lower than the response rate on the non-delay key.

PHASE II

Differential responding between keys depends on each of the two key responses being functionally different operants. If the keys were not experienced as separate, it might be expected that the effects of the negative contingency would be on overall response rate and not on relative response rate. The number of CO responses per minute was calculated. The first response of a response run on a particular key was counted, yielding an index of the number of times a subject switched, or changed over, from one key to the other. If the barrier is effective, COs per minute should decrease. Table 3 compares CO rates for sessions with and without the barrier. The barrier was only minimally effective in decreasing the rate of COs. Those five subjects which were exposed to both Phase I and Phase II averaged 13.05 COs per minute without the barrier and 11.72 COs per minute with the barrier. This effect, however, was not consistent across subjects in that only three of the five subjects showed this decrease in CO rate.

Consistent with the results observed without the barrier (Phase I), responding was not systematically decreased by the addition of the negative contingency on the left key. Response rates were, however, somewhat more

TABLE 3

Changeovers (COs) per minute for each subject and mean COs per VI value, during the last five sessions of subtractive FR 20/FR 5 and baseline recovery of Phase I and all conditions of Phase II. The key on which the contingency was presented appears in parenthesis.

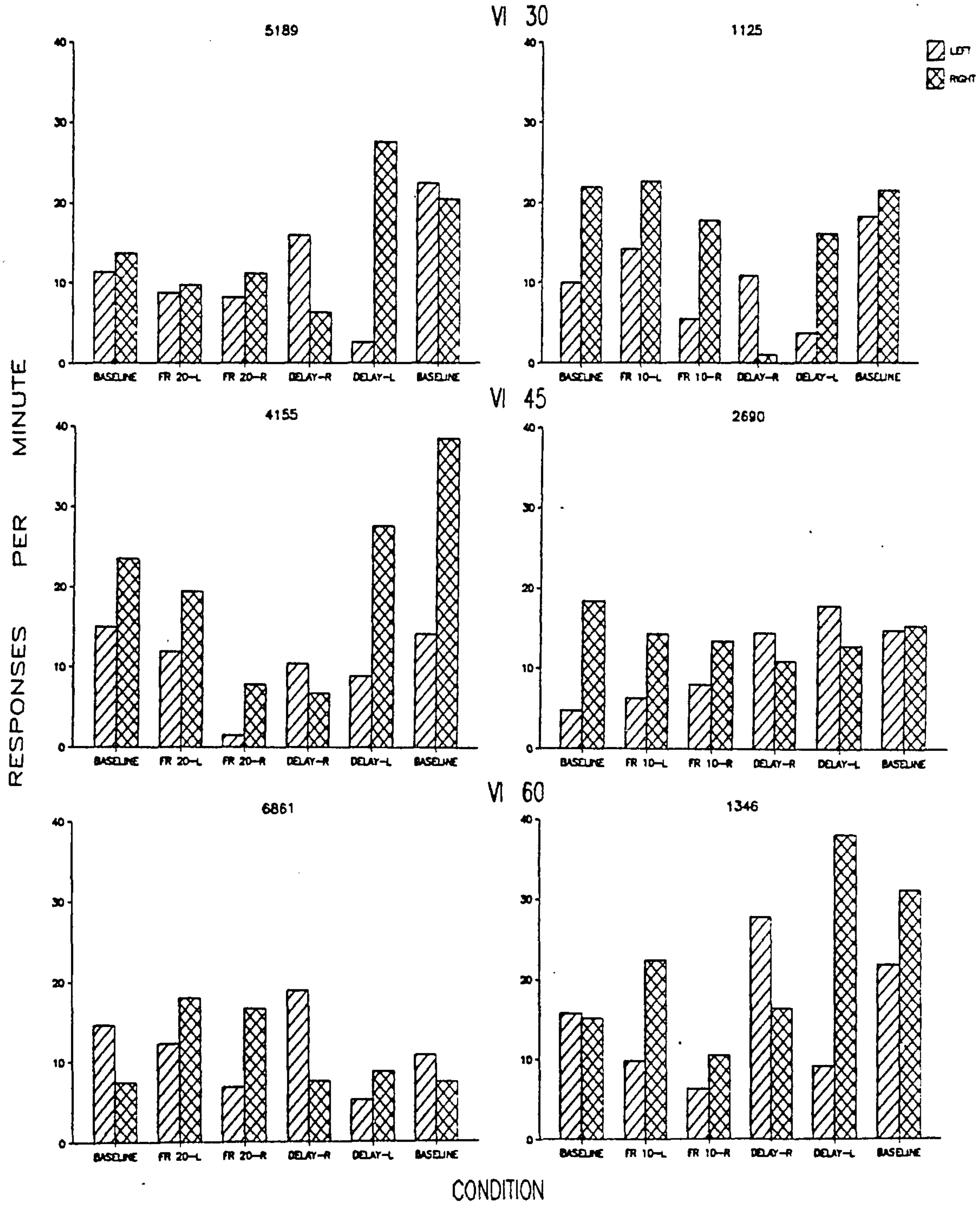
	VI 30		VI 45		VI 60	
	FR 20	FR 5/10	FR 20	FR 5/10	FR 20	FR 5/10
	5189	1125	4155	2690	6861	1346
FR (left)	8.39	6.92	14.33	4.67	13.06	4.16
MEAN	7.66		9.50		8.61	
BASELINE	4.36	11.59	11.97	11.06	10.31	20.33
MEAN	6.48		11.52		15.31	
BASELINE	9.93	15.25	13.90	8.22	9.10	12.14
MEAN	12.59		11.06		10.62	
FR (left)	9.08	15.66	12.53	7.81	13.50	5.72
MEAN	12.37		10.17		9.61	
FR (right)	8.57	5.72	1.61	5.52	8.11	5.22
MEAN	7.15		3.57		6.67	
DELAY(right)	4.78	1.74	2.68	4.06	4.92	8.17
MEAN	3.26		3.37		6.55	
DELAY (left)	4.22	4.57	6.97	4.32	3.95	5.00
MEAN	4.40		5.65		4.48	
BASELINE-H	6.02	5.94	6.46	5.12	4.54	6.42
MEAN	5.98		5.79		5.48	

variable with the barrier than without it. Figure 6 shows not only that response rates were about the same with and without the negative contingency, but also that response rates were about the same with and without the barrier (compare Figure 6 with Figure 3). Although left-key response rates were lower than right-key response rates for five of the subjects under the negative contingency, this difference was not likely due to the molar dependency. Four of these subjects had also exhibited lower left-key response rates than right-key response rates during baseline. If the subtractive FR produced an effective molar dependency, moving the negative contingency to the right key should reduce right-key responding. Three subjects did show this pattern, however, all subjects still responded more on the right key than on the left key. In fact, when the subtractive FR was moved from the left key to the right key, left-key responding decreased. This decrease is unexpected if control were by the molar dependency. However, response rates were consistently and differentially decreased on the delay key when the 2 sec delay was imposed. This was true regardless of which key the delay was presented on.

The right-key bias is clearly evident when response rates are plotted as relative frequencies, as in Figure 7. Where subjects had previously emitted about equal left- and right-key response rates, a preference for the right-key

FIGURE 6

Responses per minute on each key during the last five sessions for each subject in all conditions of Phase II.



developed with placement of the barrier. For four of the six subjects this preference became even stronger when the negative contingency was presented on the right key, contrary to what would be expected if the molar dependency was an effective contingency.

As Table 4 shows, subjects spent about equal amounts of time on the right and left keys during baseline and when the negative contingency was on the left key. When the subtractive FR was moved to the right key, subjects spent less time on the left key than on the right key. This is in accord with the observed increase in right-key preference observed in response rates. Thus the key bias seen in absolute and relative response rates is not due to the subjects responding at different rates on the keys, but is due to the differences in time that subjects spent responding on the keys.

Although the optimal rate of reinforcement was obtained during baseline sessions, the rate of reinforcement predictably decreased when the subtractive FR schedule was added, as it had done without the barrier. Figure 8 shows that some subjects obtained a higher rate of reinforcement when the subtractive FR was on the left key, some when it was on the right key. The rate of reinforcement obtained during subtractive FR conditions was about the same with the barrier as without it and was slightly higher for

FIGURE 7

Relative frequency of left-key response during the last five sessions for each subject in all conditions of Phase II.

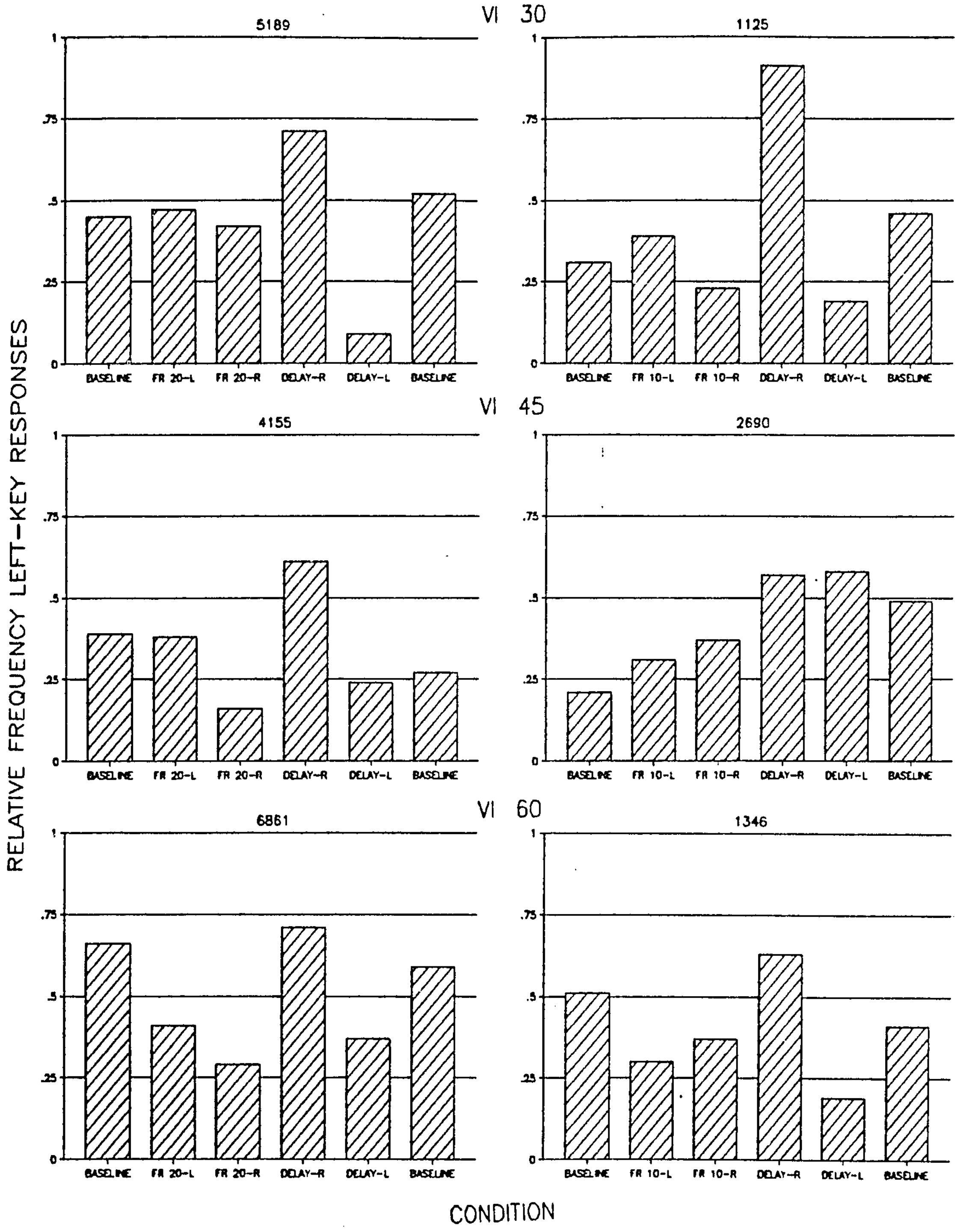


TABLE 4

Relative frequency of time spent on the left key for all subjects during the last five sessions of all conditions of Phase II. The key on which the contingency was presented appears in parenthesis.

	VI 30		VI 45		VI 60		
	FR 20	FR 10	FR 20	FR 10	FR 20	FR 10	
	5189	1125	4155	2690	6861	1346	MEAN
BASELINE	.48	.42	.51	.32	.77	.55	.51
FR (left)	.50	.46	.51	.44	.50	.30	.45
FR (right)	.37	.22	.11	.41	.40	.36	.31
DELAY(right)	.78	.85	.60	.55	.76	.64	.70
DELAY (left)	.10	.30	.34	.57	.45	.29	.34
BASELINE-H	.44	.58	.47	.48	.57	.52	.51

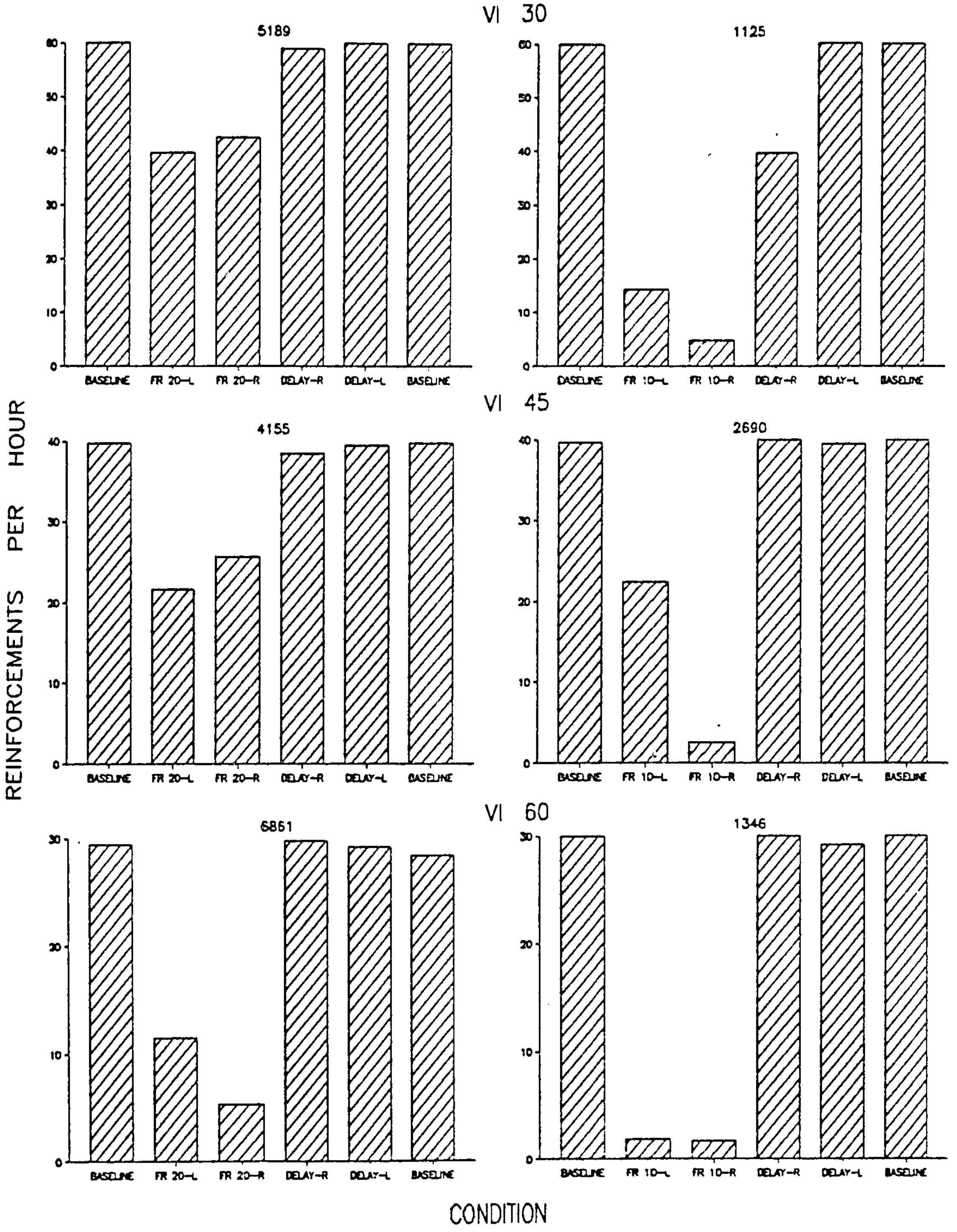
subtractive FR 10 subjects than from their previous FR 5 condition.

Overall, the molar dependency seems inadequate as a major determinant of behavior within the constraints of this schedule. Although there was differential responding between the keys, the difference was probably due to a key bias and not sensitivity to the differing contingencies. This bias existed regardless of the presence or absence of the subtractive FR. (The right-key bias seen during Phase II may have been the result of illumination differences in the chamber. That is, the houselight was in the upper right corner of the response panel. When the barrier was in place, the left side of the chamber was darker than the right side of the chamber, and the birds may have been less likely to move to the darker side).

In contrast to the lack of effect due to the subtractive FR, when the 2 sec delay of reinforcement was arranged on the right key, there was a strong and differential effect on response rates. When the 2 sec delay was on the right key, right-key response rates were lower than left-key response rates for all subjects. With the delay on the left key, left-key responding was lower than right-key responding for five of the six subjects. The differential effect of the 2 sec delay can be seen quite clearly in the relative frequency measure. Table 4 shows

FIGURE 8

Average reinforcement rates per key during the last five sessions for each subject in all conditions of Phase II. Rate is shown per key, so the maximum possible is half that provided by the schedule.



this differential effect of the delay, since most subjects began to spend less time on the delay key. The differential effect of the delay contingency is even more dramatic when it is noticed that obtained reinforcement rates were nearly at scheduled rates. In addition, the rate of COs was about the same as when the molar dependency was presented, so the chances of adventitious reinforcement or key differentibility are the same in both cases.

It seems unlikely that the observed effects of the 2 sec delay are confounded by the effects of the 2 sec hold time on the other key. When baseline conditions were reinstated with the 2 sec hold on each key, there was no consistent change in response rates. Most subjects responded about equally on both keys, and the subjects that did not respond equally showed the right-key bias.

CHAPTER IV

GENERAL DISCUSSION

Based on the results reported here and the results of Vaughan and Miller, there is little evidence that rate of behavior is influenced by the molar dependency between response rates and reinforcement rates. Although the subtractive FR schedule seems to present the ideal negative contingency, unconfounded by differential molecular inhomogeneities, response rate distributions did not show the expected shift away from the negative-contingency key when that molar dependency was presented.

In contrast, the effects of the 2 sec delay of reinforcement for responding on one key were quite apparent. Response rates on the delay key differentially decreased to an average of 70% of what response rates had been on that key. Such a decrease is really remarkable because the delay procedure used here produced a maximum 2 second delay, since responses during the delay did not reset the delay timer. This means that delay-key responses could be contiguous with food delivery and that the average delay was probably less than 2 seconds. (Williams, 1973, also used this type of delay arrangement in a single-key, nonchoice procedure and found comparable decreases in response rates). A delay of less than 2 seconds was enough to change behavior, but a change in the correlation between molar response and reinforcement rates from near 0 to -.94 was not enough to alter behavior.

The goal of this study was to present subjects with a molar response dependency which arranged a negative correlation between rate of key pecking and rate of response-dependent food deliveries to see if this contingency would, to any degree, differentially decrease key-peck rate. These results suggest that the negative molar dependency is not an effective contingency. The schedule used was a concurrent VI VI schedule where the negative contingency was presented on only one of the keys. To the extent that behavior on this conc VI VI schedule is controlled by the same variables as behavior on other conc VI VI schedules (i.e., conc VI VI schedules with positive correlations), then these results should be applicable in general to interpretation of control of behavior by conc VI VI schedules. Although a number of authors have shown that it is possible, in principle, that sensitivity to molar dependencies could account for matching on conc VI VI schedules (e.g., Rachlin, Green, Kagel, and Battalio, 1976), the lack of evidence of such sensitivity seriously questions the validity of such interpretations (cf. also Heyman and Herrnstein, 1986, for a recent review).

Before dismissing the molar contingency completely, however, the procedure deserves closer scrutiny. Is there anything within the procedures used which may have either prevented control by the molar dependency or promoted control by temporal contiguity?

OBTAINED CORRELATIONS

If the correlations between the emitted response rates and the resulting reinforcement rates were effective in determining future response rates, then the observed response distribution should have shown a decrease on the subtractive FR key in the current concurrent schedule, provided that the subjects actually experienced a negative contingency. The negative contingency should have been experienced if the response rate distributions varied sufficiently to affect reinforcement rates. A conservative estimate of experienced correlations could be obtained by plotting obtained reinforcement rates over obtained response rates in the form of a scatter plot. In determining these correlations, the rates of left- or right-key responding and the total rates of reinforcement per session were used. A perfect negative correlation, -1.0, would indicate a consistent relationship in which the higher the key-response rates the lower the overall rate of reinforcement. Tables 6 and 7 show correlation coefficients for both the left and right keys during the last 10 sessions of the subtractive FR

TABLE 5

Correlation coefficients for each key for the last ten sessions of FR 20/FR 60, FR 20/FR 5, and baseline recovery of Phase I. The key on which the contingency was presented appears in parenthesis.

	VI 30		VI 45		VI 60				
	FR 20	FR 60/5	FR 20	FR 60/5	FR 20	FR 60/5		FR 20	FR 60/5
	76	1125	4155	2690	6861	1346	MEAN	MEAN	MEAN
FR (left)									
right	-.16	.23	.31	.19	-.79	-.34	-.09	-.21	.03
left	-.07	.09	-.79	-.20	-.99	-.93	-.48	-.62	-.35
FR (left)									
right	-.35	-.46	-.91	.17	-.83	.28	-.35	-.70	-.003
left	-.96	-.87	-.99	.26	-.92	.10	-.56	-.96	-.17
BASELINE									
right	.01	-.46	.03	.17	-.64	-.38	-.21		
left	-.30	.09	-.30	-.04	-.14	-.36	-.18		

and baseline recovery conditions of Phase I and all conditions of Phase II, respectively.

During the subtractive FR 20/FR 60 sessions of Phase I, the correlation for left-key responding and overall rate of reinforcement was generally a stronger negative correlation for the FR 20 subjects than for the FR 60 subjects. This would be expected due to the constraints of the schedule. The data also show that, in general, the higher the scheduled rate of reinforcement, the lower the correlation. This would also be expected due to the constraints of the schedule.

The change from the subtractive FR 60 to the subtractive FR 5 of Phase I or subtractvie FR 10 of Phase II was supposed to make the correlations between left-key responding and overall reinforcement rates stronger. It did not have this effect. Response rates remained high and many foods were cancelled, so that the subjects may never have contacted the negative correlation. More exactly, with the FR 5 and FR 10 schedules, a large portion of possible response rates would result in few foods for a particular session. It was only when the negative-contingency-key response rate was fairly low, less than 5 or 10 responses per minute, that there was a true negative correlation between response rate and reinforcement rate. All response rates higher than this subtracted so many foods that rarely

TABLE 6

Correlation coefficients for each key for the last ten sessions of all conditions of Phase II. The key on which the contingency was presented appears in parenthesis.

	VI 30		VI 45		VI 60				
	FR 20	FR 10	FR 20	FR 10	FR 20	FR 10		FR 20	FR 10
	5189	1125	4155	2690	6861	1346	MEAN	MEAN	MEAN
BASELINE									
right	-.50	.62	-.32	-.55	-.02	-.40	-.20		
left	-.31	-.09	-.14	.16	-.13	.22	-.05		
FR (left)									
right	-.04	-.01	-.63	-.09	.43	-.02	-.06	-.08	-.04
left	-.68	-.83	-.97	-.98	-.98	-.42	-.81	-.88	-.74
FR (right)									
right	-.90	-.87	-.98	-.39	-.94	.19	-.65	-.94	-.36
left	-.13	.10	-.44	-.03	.30	.21	.002	-.20	.09
DELAY (right)									
right	.46	.66	.26	-.31	.47	.40	.32		
left	.26	.81	.26	.25	.16	-.21	.26		
DELAY (left)									
right	.17	-.04	.06	-.29	-.34	.10	-.06		
left	.54	.12	-.18	-.11	-.46	.37	.05		
BASELINE-H									
right	.14	-.05	.56	-.06	.53	.17	.22		
left	.14	-.26	.31	-.46	.64	.75	.19		

was there a food delivery. The lower the scheduled rate of reinforcement, the more constrained was the range of effective response rates, as Figures 6 and 7 attest to.

With no scheduled correlational contingency on the right key, the average obtained correlations should have been close to 0. Some of the subjects showed negative correlations, and some showed positive correlations between right-key rate of responding and overall rate of reinforcement during the subtractive FR conditions. These right-key correlations were weaker (i.e., closer to 0) than left-key correlations, as they should have been.

During delay conditions, correlations tended to be positive and, in a few cases, fairly strong. The mean correlations between response rates on the delay key and overall food rates were somewhat higher than the mean correlations between non-delay-key response rates and overall food rates. In addition to the lack of a differential effect of the subtractive FR, this finding diminishes the confirmation of a molar correlational account since response rates were lower on the delay key than the non-delay key.

In support of a molar-dependency account of behavior, one could argue that it may be unfair to evaluate the effective correlation as was done here. As Baum (1973) points out, an organism samples over some time period response rates and reinforcement rates. The effective correlation between these two rates will, then, be affected by the time period over which they are sampled. It is doubtful that the subject's sampling period is equal to the session length. If a shorter sampling period were used to calculate correlations it may be found that the relationship between response rates on the negative-contingency key and reinforcement rates was not as strong a negative correlation as found in Tables 5 and 6.

There are two replies to the possibility that organism's did not experience the proposed molar contingency due to a smaller sampling period. First, how is the sampling period to be specified? Williams (1976) offers one method for estimating the sampling time, and concludes that it must be in the range of 3 - 5 sec, but he discounts the utility of such attempts. Not only must specification of the sampling period necessarily be defined from the data, post hoc, but there is no reason to believe sampling time is a fixed period (as opposed to a distribution of sampling times). In such a case it becomes nearly impossible to independently determine the mechanism by which the organism responds to its environment. This definitely detracts from the appeal of a molar dependency account of behavior.

The second reply to the possibility that the organisms did not experience the proposed molar contingency is that this is exactly the molar contingency which most advocates of this viewpoint would expect to be effective. Similar procedures have been used to show the primacy of the molar dependency over molecular contingencies except that both concurrent components produced a positive correlation between response and reinforcement rates. Without a reasonable interpretation of why a negative molar contingency should be less effective than a positive molar contingency, acceptance of the effectiveness of a molar contingency is difficult.

It might be possible to maintain the position that the molar dependency between response and reinforcement rates is an effective contingency, but that in the current procedure subjects did not differentiate left from right key pecks. If, even with the physical barrier in place, subjects were 'confused' as to which key had just been pecked, then a decrease in overall responses rates (with equal rates on both keys) instead of a shift away from the subtractive FR key, might be expected. This would be true because lower overall response rates would still be the response rate which produced the highest rate of reinforcement. Figures 3 and 6 offer some support for this interpretation in that overall response rates did occassionally decrease from baseline to subtractive FR conditions. Most especially, the subtractive FR 5 and FR 10 conditions produced the lowest overall responses rates and the lowest overall reinforcement rates. But there are some problems with this interpretation. First, overall response rates during the delay conditions were decreased for some subjects, yet relative response rates did not remain equal. If the concurrent schedule produced key confusion, it seems that presentation of the 2 sec delay should increase confusion, not decrease confusion. During delay conditions either a left, a right, or no key peck could immediately precede food delivery, but in the subtractive FR conditions the dependent-key response was always the response which immediately preceeded food delivery even if an opposite-side-key response had been emitted shortly before. Second, the molar dependency has been used as an explanation for response distribution shifts in the more typical conc VI VI schedules. It is not obvious why the concurrent schedule used here would produce confusion where the other concurrent schedules do not.

BLOCKING OF CONTINGENT CONTROL

The ability of a particular contingency to control behavior probably has both biological and environmental predeterminants. For the purposes of discussion, assume that there is a biological predisposition for control by both the molar and molecular contingencies. What type of behavioral history might be necessary to promote control by the molar contingency? The usual procedure for preparing subjects is to shape the desired behavior, beginning with simple units of existing behavior, and gradually to require approximations to the desired behavior. Specifically, pigeons are accomodated to the chamber and hopper trained so that they approach the hopper when grain is available. Grain delivery is then made dependent on the subject's behavior: looking at the key, approaching the key, and finally pecking the key. Most importantly, food is always delivered immediately following the desired response. Although this method may be desireable for establishing contact with most schedules (i.e., temporal contiguity), it may not be the most effective method for establishing contact with a molar dependency. To establish control by a molar contingency it may be that different precursor behaviors must be shaped. That is, sensitivity to a molar contingency may require a behavioral history which is different from that required by sensitivity to a temporal contiguity contingency. In the present study and in Vaughan and Miller's study, experienced subjects were used, and these subjects were originally hand-shaped in the typical manner. The usual shaping procedure may actually 'block' control by molar contingencies.

To see how this might work, consider the basic blocking phenomenon (Kamin, 1969). When a stimulus, say a light, consistently precedes a response-independent reinforcer, conditioned respondent behavior will occur during future presentations of the light. If a compound stimulus, say a light and a tone, consistently precedes a response-independent reinforcer, responding will occur when either the light or the tone are present alone. But, if during several pretraining trials, the light alone is presented before food and then the light/tone compound is presented, no responding will occur when the tone is presented alone. The pretraining of the light blocks control by the tone. Perhaps the hand-shaping of subjects or the baseline conditions used here where temporal contiguity between key pecking and food delivery was all-important is like the pretraining of the light. When the compound stimulus was later presented (molecular temporal contiguity and the molar negative contingency), control by the negative contingency did not occur because such control had been blocked. If temporal contiguity were not as important in the shaping or baseline conditions, control by the molar contingency may have developed. A parallel argument was expressed by Williams (1983), only in terms of blocking of temporal contiguity by an 'information' variable instead of blocking of the molar dependency by temporal contiguity.

Another possibility is to consider how the schedule was introduced. In the present study and in Vaughan and Miller's study, once the baseline linear VI schedule had been established, the FR values were added. As Tables 6 and 7 show, the subtractive FR schedules presented here did not always produce a strong negative correlation. However, in those conditions where the negative contingency was presented, it was always true that a key peck immediately preceded food delivery. Perhaps if perfect correlations were introduced first, and then gradually reduced to less than -1.0, the negative contingency would be more effective in controlling responding.

Analogous situations have been studied by Wagner (1968), and by Mazur and Logue (1978). Wagner found that when a compound stimulus (a light and a tone) was presented before a reinforcer, control by the tone depended on the 'validity' of the tone as a predictor of food. Specifically, if the light alone was presented on some trials without the tone before food, little responding occurred in the presence of the tone. When the light alone was presented but never followed by the reinforcer, a high rate of responding occurred in the presence of the tone. The amount of responding to the tone was an increasing function of the 'predictiveness' of the tone. In the present study it may be that the negative correlation was not a strong enough correlation to override (or the molar dependency was not more predictive than) the consistency of temporal contiguity. [Another way to think of this may be in terms of saliency. The more salient the stimulus element, the more conditioning occurs to that element and the lower the rate of responding to other elements within the compound (Mackintosh, 1978). If temporal contiguity were more salient than a molar dependency, then there may be little control by the molar contingency].

Mazur and Logue were working with a very different paradigm. They were looking at 'self-control', where pigeons were given a choice between a small, immediate food and a large, delayed food. Usually, pigeons choose the immediate food, but by presenting both the small and large foods immediately after a response and gradually increasing the delay to the large food across sessions, Mazur and Logue found preference for the large delayed food. Thus, perhaps by initially presenting a strong negative correlation and then gradually fading in a weaker correlation, the molar contingency could become effective.

These studies lend support to the idea that exposure to a contingency where food is delivered only immediately following a response may interfere with later control by a molar dependency between overall response rates and overall reinforcement rates. This lack of control may be compounded by presenting weak correlations between response rates and reinforcement rates. It is important to recognize, however, that if this should be the reason no sensitivity to the negative contingency was seen here, then the molar dependency between response and reinforcement rates must be a fairly weak, subsidiary contingency in typical operant conditioning preparations such as those that have compared response rates between VI and VR schedules. Explicitely, the possibility that temporal contiguity can block control by a molar dependency is important for determining whether the molar contingency can ever be an effective contingency. However, this was not the question specifically addressed with the concurrent schedule used here. The present study was designed to address the question of whether a molar dependency, where the reinforcement rate decreased as rate of responding on one of the two keys increased, could shift responding off that particular key. The same molar dependency has been used as an alternative explanation to molcular response strengthening for explaining why concurrent responding shifts from one key to the other when the programmed schedule values, or the relative rates of reinforcements, are changed. Unless the view is taken that sensitivity to positive correlations is stronger than sensitivity to a negative correlation between response and reinforcement rates, it seems doubtful that the observed response rate differences found between conc VI VR schedules (or other conc VI VI schedules) could be due to the molar dependencies.

MAXIMIZATION

Although the present data do not completely rule out the effectiveness of a molar contingency, it seems clear that pigeons do not maximize rate of food delivery in terms of amount of grain over time. The same conclusion was drawn by Vaughan and Miller. But these were not the first studies to cast doubt on such a proposal (for instance, see Herrnstein and Heyman, 1979; and Heyman and Herrnstein, 1986). Still, proponents of maximization abound. Although an in-depth analysis of maximization is far beyond the scope of this paper, it does seem appropriate to briefly consider the appeal of a maximizing principle and why this leads to acceptance of a molar-dependency account.

In order for organisms to survive, they must maintain numerous biological requirements. Those organisms which can maintain a higher level of these requirements than other organisms in that situation, will be the more successful reproducers. This is the common sense basis for accepting a maximizing theory-- organisms which forage optimally, getting the highest rate of food with the least effort, will be the most likely to survive and reproduce. Molar maximizing (or the selection of a particular response rate) may, in some ways, be analogous to foraging strategies and rate of reinforcement analogous to net energy yield (Lea, 1981, 1982). Parsimony between the various principles of behavior is very attractive and to the extent that parallel principles can be found, a continuity between behavior at different levels is established.

Maximizing is a global behavioral outcome, not a particular mechanism. An optimal forager is one which, in the long run, obtains the highest amount of food possible from the environment. If the commodity to be maximized is rate of food, then rate of food should be a selective factor for the particular operating mechanism. One possible mechanism is the relationship between response rates and reinforcement rates. Baum's correlational law of effect is one possible mechanism.

Assume rate of food is an appropriate dimension of maximizing. If the organism is obtaining enough food to maintain, but could actually obtain more food from the environment by following a different foraging strategy, will there be natural selection for an alternative foraging mechanism? It is this point which most opponents of maximizing address. Baum (1982b) worded this idea nicely when he wrote:

> Organisms can follow a relatively simple fixed rule that works in most situations, even if it is sometimes nonoptimal... Natural selection may have produced individuals that follow less complicated principles than optimization, even though natural selection tends to optimize. Simple approximations to optimality require less effort and less machinery. (p 228)

If a simple mechanism, like control by temporal contiguity, sufficed in most natural foraging situations, would a more complicated mechanism like control by molar dependencies ever be selected? How much of an advantage would be necessary for a molar contingency to be more effective than temporal contiguity? Assuming that control by a molar contingency in some way 'costs' the organism more than control by temporal contiguity (speculatively, this could be in terms of a higher energy cost for operation of the mechanism, or molar contingencies could be a more difficult discrimination than simple contiguity, etc.), there should be some trade-off between this cost and the relative advantage of that mechanism as to which mechanism were ecologically selected for. In fact, there may be selective pressure for the simplier 'rule of thumb' over the more complicated maximizing mechanism if, by following this rule of thumb, nutritional requirements were met with more time and energy to devote to other activities.

Baum (1982b) suggests another interesting possibility. If organisms must meet certain requirements over some time interval, T, then the mechanism for meeting these needs will depend on T. That is, if T is short, molecular changes in food rate will have a great impact on survival. However, if T is long, short-term rate changes will have less of an effect on foraging behavior. (In many ways T is like the sampling period discussed earlier, and the same comments apply).

As with the possibility that exposure to one contingency may block control by another contingency, the present study does nothing to illuminate the necessary conditions for selection of a particular contingency. The present study does, however, shed some light on the outcome of the operating mechanism. This outcome is not generally optimal; these subjects did not maximize. When the negative contingency was presented, reinforcement rate dropped drastically, and all subjects required supplemental home-cage feedings. Response rates remained about equal on the two keys, an outcome closer to matching than maximizing (Herrnstein, 1970). Although it may not be possible to conclude that a molar contingency is never effective in controlling behavior, it seems highly improbable that maximizing rate of food is the explanation of performance in most situations.

It may be that what is maximized is not just rate of food, but a 'package' of commodities (Rachlin, et.al., 1981). Such packages are commonly defined as food and leisure, where leisure is all behavior not required for key pecking. Thus, the higher the rate of key pecking, the less time there is for leisure. With most schedules (i.e., schedules where there is a positive correlation between rate of responding and rate of reinforcement), this leads to a trade-off between rate of reinforcement and amount of obtainable leisure. In the current schedule, however, the lower the rate of responding, the higher the rate of reinforcement and the more time available for leisure. Such a conception of behavior does little to explain why subjects continued to respond at a high rate when by decreasing response rate, more food and more leisure could have been obtained. The only explanation from this viewpoint seems to be that key pecking itself is one of the commodities in the package, but this would be contrary to the usual assumption that work is aversive. Thus, it seems very difficult to explain behavior on this schedule from an appeal to maximization at a molar level.

SUMMARY

In the present study subjects were presented with two response contingencies. One of the contingencies established a close temporal relationship between key pecks and food delivery in that food was only delivered immediately following a response. The second contingency established a molar dependency between key pecking and food delivery where the lower the rate of responding, the higher the rate of food. If the molar contigency had been effective, then there would have been at least two explanations to consider. 1). Multiple contingencies can be effective within any particular situation and these contingencies can affect different response dimensions. The resulting behavior should, then, be a combination of contingent effects. 2). Temporal contiguity may not be the primary contingency operating on behavior and a different framework, such as an overall maximizing principle or a molar contingency, need be entertained as a more accurate conception of behavior.

The results showed no effect of the molar contingency, but did show a distinct effect of the temporal contiguity contingency. In that these subjects did not maximize, acceptance of a maximizing principle seems unwarrented, no matter how theoretically appealing the approach may be. It seems equally difficult to accept a contingency based on the molar dependency between response and reinforcment rates as an explanation for behavior control in situations similar to the one presented here. It is not, however, as easy to dismiss multiple contingencies as factors in behavior control from the present data. Although the schedule used here adds to the list of situations under which control by a molar dependency is not found, there may be factors which prevented such control. This is an empirical question, and by careful manipulation of the pretraining conditions and adjustment of the relative saliency of the contingencies, conditions more favorable to a molar contingency can be established. It remains to be seen if a molar dependency can ever be an effective contingency.

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