

*THE EFFECT OF PHYSICAL RESTRAINT ON BEHAVIOR  
UNDER THE DIFFERENTIAL-REINFORCEMENT-  
OF-LOW-RATE SCHEDULE<sup>1</sup>*

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Previous studies have identified and manipulated collateral behavior to assess the effect of collateral behavior on performance under the differential-reinforcement-of-low-rate (DRL) schedule. However, conclusions could not be applied to subjects not observed to engage in collateral behavior. The present study used a technique that prevented the occurrence of the types of collateral behavior typically observed in the pigeon. This technique did not require the identification of collateral behavior in the subjects. The exclusion of the types of collateral behavior typically observed in pigeons resulted in higher response rates and lower reinforcement rates under large DRL values but had no effect at lower DRL values. It was concluded that collateral behavior is necessary for low response rates and high reinforcement rates under large DRL values.

The differential-reinforcement-of-low-rate (DRL) schedule requires spacing of responses; the time interval between response  $n$  and response  $n + 1$  (the interresponse time) must equal or exceed some specified value if response  $n + 1$  is to be reinforced. Wilson and Keller (1953) first noted consistent patterns of behavior (collateral behavior) occurring between operant responses on the manipulandum reinforced according to a DRL schedule. Their explanation of the collateral behavior in terms of an adventitiously reinforced behavioral chain assigned the collateral behavior an important role in spaced responding. Later studies attempted to quantify and manipulate collateral behavior in order to study the relation of collateral behavior to DRL performance. Segal-Rechtschaffen (1963), Davis and Wheeler (1967), Zuriff (1969), and McMillan (1969) used reinforcement to establish responding on one manipulandum that could serve as collateral behavior for a DRL schedule arranged on a different manipulandum. Laties, Weiss, and Weiss (1969) ob-

tained reliable collateral behavior in rats by simply providing blocks of wood on which the rats could chew. Laties, Weiss, Clark, and Reynolds (1965) and Hodos, Ross, and Brady (1962) studied collateral behavior that developed accidentally while the subjects were being trained on a DRL schedule for other purposes.

All of the studies cited above found that preventing collateral behavior, however it developed, affected the subjects' performance on the DRL schedule; generally, the prevention of the collateral behavior resulted in a larger ratio of responses to reinforcements. Thus, these studies adequately demonstrate that collateral behavior does, in some cases, play an important role in spaced responding behavior. However, they do not show that all DRL behavior with a small ratio of responses to reinforcements depends on concurrent collateral behavior.

These studies identified and manipulated specific patterns of collateral behavior. This approach has not been able to answer the more general question: is collateral behavior necessary in order for a small ratio of responses to reinforcements to occur during DRL performance? A problem stems from the necessity of identifying the specific pattern of collateral behavior in each subject. Often, subjects have a small ratio of responses to reinforcements on the DRL schedule without showing identifiable, consistent patterns of behavior that can be classified by

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the experimenter as collateral behavior (Kelleher, Fry, and Cook, 1959). This failure to identify collateral behavior does not necessarily mean that collateral behavior is not present; perhaps the test for collateral behavior (observation by the experimenter) is simply not sensitive enough to detect such behaviors in some animals. There are several reasons why this may be true. First, the collateral behavior tends to drift, to change over time because the form of the collateral behavior is not specified by the experimental contingencies, and one form of collateral behavior may serve as well as another. Second, it is possible that a subject may display several patterns of collateral behavior and that the particular pattern varies from one IRT (interresponse time) to the next. Third, perhaps some patterns of collateral behavior are not distinctive enough for the experimenter to identify reliably through casual observation. Hodos *et al.* (1962) remarked that observed collateral behavior may represent only a fraction of some more complex pattern.

Kramer and Rilling (1970) suggested that a more fruitful approach to the study of collateral behavior during DRL performance would be to eliminate the occurrence of collateral behavior by the use of curare, a drug that blocks nerve transmission to skeletal muscles. However, the paralysis would require the use of an autonomic response system as the reinforced operant; the generalization of the results to the skeletal responses typically studied would be tentative. Also, it would be desirable to compare the DRL behavior with and without the availability of collateral behavior, and this would be difficult or impossible with an autonomic operant, as movement interferes with the recording of autonomic responses and may mediate autonomic responses.

Glazer and Singh (1971) prevented collateral behavior in rats by enclosing the rat's body in a box that prevented all movement except the up and down movements of the head, which constituted the reinforced operant. Stable responding under a DRL 10-sec schedule did not differ in rate between the restrained and non-restrained groups. However, when the number-of-reinforcements and the interresponse-times-per-opportunity functions were considered, restrained rats were grossly inferior to non-restrained rats.

In the present study, physical restraint was used to reduce skeletal movement, completely preventing locomotion, wing flapping, and other gross body movements in pigeons. These are the classes of behaviors most typically identified as collateral behaviors in the pigeon. It was expected that when physically restrained, the subjects would respond at a higher rate and obtain a lower rate of reinforcement due to the lack of competing collateral behaviors.

## METHOD

### *Subjects*

Four naive, adult, homing pigeons were maintained at 70% of their free-feeding weight during preliminary training and at 75% during the remainder of the experiment.

### *Apparatus*

The birds were tested in four identical operant chambers with the following inside dimensions: 52 cm long, 36 cm wide, and 38 cm high. The response panel in each test chamber had a key hole 2.5 cm in diameter centered 27 cm above the floor. The response key was a translucent Plexiglas paddle. The rear side of the paddle was painted flat black except for a circle 1 cm in diameter, which was centered behind the key hole. The paddle was transilluminated with white light. A force of 15 to 20 g (0.15 to 0.20 N) with an excursion of 0.1 cm was required to operate the response key. The houselight consisted of two 28-V bulbs placed behind a Plexiglas screen located across the top of the response panel. The reinforcer was one 45-mg Noyes pigeon pellet delivered to a Scientific Prototype food tray centered 7.7 cm below and 5 cm to the left of the response key. A 28-V shielded bulb located 5 cm above the food cup directed light into the food cup for 1 sec when a reinforcer was delivered. A 90-dB white masking noise was continuously present in the test chamber.

Physical restraint was enforced by placing the bird inside a box 13 cm wide, 15 cm long, and 10 cm high with a hole 4.8 cm in diameter located in the front of the restraint to allow the bird's head to protrude. The rear half of the top of the restraint pivoted down to hold the bird firmly in the restraint. The restraint was mounted on a pedestal and placed in the

operant chamber so that the bird's head appeared to be in the same position as a non-restrained bird's when pecking the key. The bird's beak was approximately 1.5 cm from the key when in the resting position.

An IBM 1800 Data Acquisition System located in a separate room controlled the experimental contingencies and recorded responses.

#### Procedure

Birds 260 and 261 were in the restraints during the experimental sessions starting with the first day of adaptation. Birds 262 and 263 were free moving in the chambers, *i.e.*, they were not in the restraints. All birds were adapted to the test chambers, magazine trained, shaped to respond and pre-trained for three sessions in which every response was reinforced. This was followed by two sessions of DRL 5-sec and two sessions of DRL 10-sec. Then, the experiment proper began. All birds were trained under DRL 15-sec for 36 sessions of 60 min each. Next, the conditions were reversed, *i.e.*, the birds previously trained under the restrained condition were changed to the free condition, while the subjects previously trained under the free condition were placed in the restraints. After 20 sessions, the birds were returned to the original conditions for 14 more sessions of 60 min and six sessions of 30 min each.

Table 1

Experimental conditions in the order of occurrence  
R = restrained and F = free.

Subjects		DRL	Session	Number
260 and 261	262 and 263	Value (Sec)	Duration (Min)	of Sessions
R	F	5	32	2
R	F	10	45	2
R	F	15	60	36
F	R	15	60	20
R	F	15	60	14
R	F	15	30	6
R	F	10	30	12
R	F	10	20	10
R	F	5	20	14
R	F	3	12	18
R	F	0	4	24
F	R	0	4	10
F	R	3	12	20
F	R	5	20	12
F	R	10	30	16
F	R	Extinction	120	4

Next, the birds were tested on different DRL values in the order 10, 5, 3, 0, 3, 5, and 10 sec (see Table 1). Birds 260 and 261 were restrained during the descending series and were free during the ascending series. Birds 262 and 263 were free during the descending series and restrained during the ascending series. All birds were tested in both the free and restrained conditions on DRL 0-sec. Finally, extinction was scheduled, *i.e.*, no responses were reinforced. The session lengths under the different DRL values were selected to be as long as possible without producing weight gains in the subjects except for DRL 15-sec, which had the session length arbitrarily set at 60 min. DRL values were changed when the response rates of all subjects were judged to show no consistent trend over a five-day period.

The DRL schedule reinforced every response with an IRT equal to or greater than the DRL value. The IRTs were measured as the time from the beginning of the session to the first response, and, thereafter, as the time between two successive responses. At the start of the session, the houselights and stimulus lights were illuminated and remained illuminated until the end of the session, when all lights were extinguished.

## RESULTS

Figure 1 presents response rates and reinforcement rates of the birds as a function of blocks of two sessions for the DRL 15-sec training. Response rates were higher, and reinforcement rates were lower, in the restrained condition than in the free condition. There was no effect of order of presentation of the conditions. When exposed to a condition for the second time, the birds tended to recover the original response rates and reinforcement rates. Within a condition, changes in response rate across sessions tended to be inversely related to changes in reinforcement rate. One notable exception was Bird 262 during the second exposure to the free condition; rate of reinforcement doubled but there was no concurrent change in response rate. The birds restrained for the first condition showed an increase in response rates and a decrease in reinforcement rates across sessions. The birds that were free as the first condition showed either a decrease in response rate and an in-

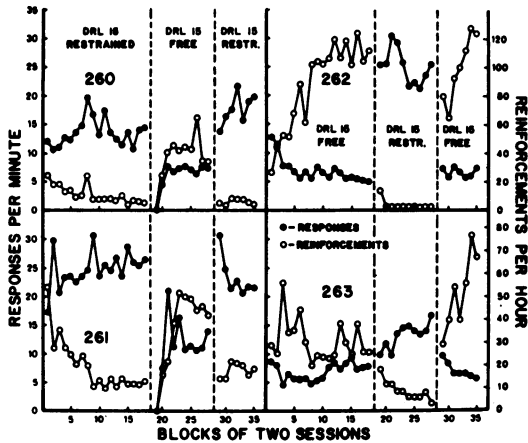


Fig. 1. Mean response rate (closed circles) and reinforcement rate (open circles) per two-session blocks under the DRL 15-sec schedule with a 1-hr session length. Left panel: first condition; middle panel: second condition; right panel: repeat of the first condition. The two graphs on the left contain the data of the birds that were restrained as the first condition. The two graphs on the right contain the data of the birds that were free as the first condition.

crease in reinforcement rate across sessions (Bird 262), or no change in response rate or reinforcement rate across sessions (Bird 263) within the first condition. The birds that were restrained as the first condition stopped responding when placed in the free condition, and were shaped to peck by the experimenter after two sessions of no responding. This accounts for the zero rate in block 19 of Birds 260 and 261. When the conditions were switched, there was an immediate change in response and reinforcement rates for all birds.

Figure 2 presents responses per reinforcement-

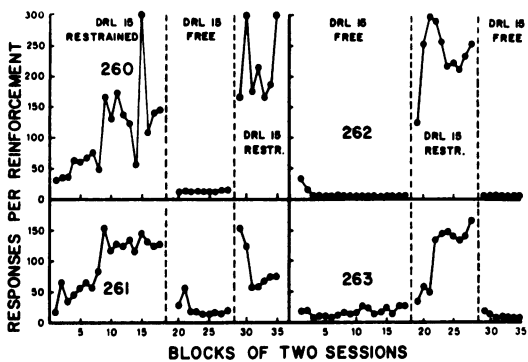


Fig. 2. Mean responses per reinforcement in each block of two sessions under the DRL 15-sec schedule. All details are the same as in Figure 1.

ment as a function of two-session blocks for the DRL 15-sec training. The first condition shows a strong effect of training for the restrained birds but not for the free birds. The restrained birds showed a large increase in responses per reinforcement as training progressed, with an initial performance of approximately 50 responses per reinforcement rising to an asymptotic level of approximately 150 responses per reinforcement. The birds in the free condition maintained a low value of approximately 15 responses per reinforcement from the first sessions of DRL 15-sec training. There was a large immediate decrease in responses per reinforcement to a stable level when a bird was changed from the restrained to the free condition. (There is no datum point for block 19 of Birds 260 and 261 because these birds made no responses during those two sessions.) When birds were changed from the free to the restrained condition, the change to the terminal level of responses per reinforcement was more gradual for all birds except Bird 260.

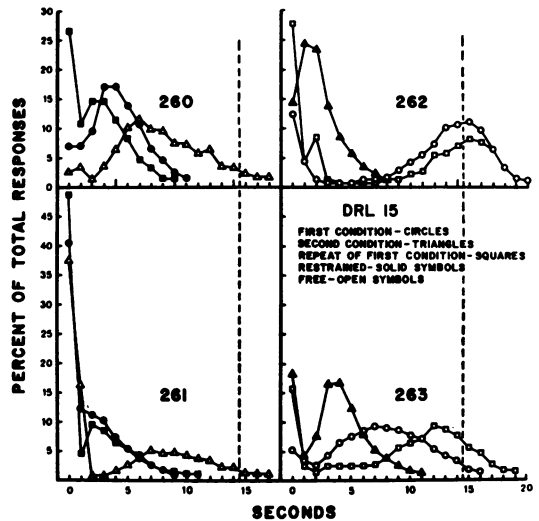


Fig. 3. IRT distributions for each of the three conditions under the DRL 15-sec schedule with a 1-hr session length. Each distribution is an average of the last five days of the condition. The numbers on the abscissa represent the lower limit of IRT classes 1 sec wide, e.g., 0 contains all IRTs from 0.00 through 0.99 sec in duration. Circles represent the first condition, triangles represent the second condition, and squares represent the repeat of the first condition. Solid symbols represent the restrained condition. Open symbols represent the free condition. The right-most point plotted for each function is the last IRT class containing more than 1% of the total IRTs. IRTs to the right of the vertical dotted line were reinforced.

Figure 3 presents the IRT distributions for each bird under each condition during the DRL 15-sec training. Several of the distributions are bimodal, with a high frequency of IRTs shorter than 1 sec (bursting). These short IRTs do not show an effect of conditions. However, if the short IRTs are ignored, there is a clear effect of training conditions on the location of the mode of the IRT distribution. For each bird, the mode of the IRT distribution occurred at a higher value in the free condition than in the restrained condition. The effect of restraint was to cause a large shift of the IRT distribution to the left.

Figure 4 presents the mean response rates under each DRL value for the free and the restrained conditions. Response rates decreased as the DRL value increased for birds in the free condition, with the exception of an increase at DRL 10-sec for Bird 261. When in the restrained condition, response rates decreased as the DRL value increased up to

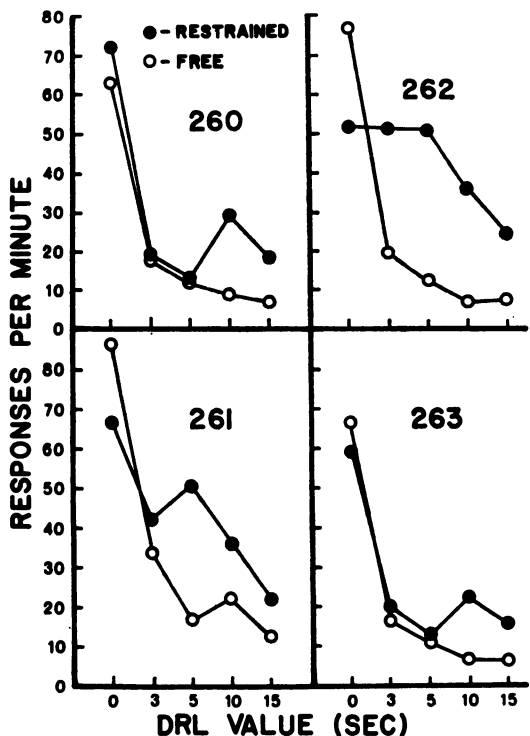


Fig. 4. Mean response rates under the restrained (solid circles) and the free (open circles) conditions as a function of DRL value. Each point represents the mean of the last five days under that condition. The last five days at the longest session length were used for DRL 15-sec and DRL 10-sec schedules.

a point. At this point, the response rates increased with an increase in the DRL value for all birds except Bird 262. This increase in response rate occurred at DRL 10-sec for Birds 260 and 263 and at DRL 5-sec for Bird 261. Before this break and from this break on, response rate was a monotonically decreasing function of DRL value in the restrained condition. At DRL values below the break, Bird 260 responded at the same rate in the free and restrained conditions. Bird 263 also failed to show an effect of restraint on response rate at DRL values below the break. Both Bird 261 and Bird 262 responded at a higher rate in the free condition when under the DRL-0 sec schedule. At all other DRL values Birds 261 and 262 responded at a higher rate in the restrained condition.

In order to compare the rate of reinforcement obtained in the free and restrained conditions, a relative measure was computed by dividing the number of reinforcements obtained under a DRL value in the free condition by the number of reinforcements obtained under both the free and restrained conditions for that DRL value. This statistic, the relative proportion of reinforcements obtained in the free condition, is presented in Figure 5 as a function of DRL value (open circles, right side ordinate). During the DRL 0-sec schedule, all birds received the

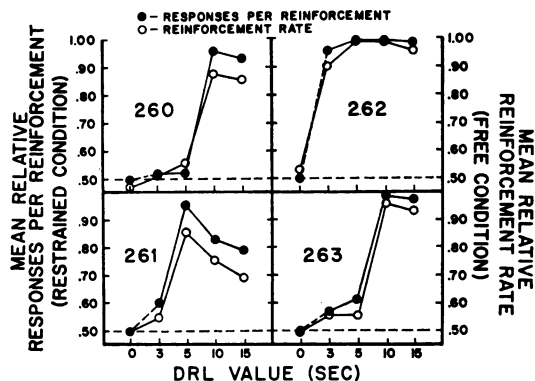


Fig. 5. Mean relative reinforcement rate in the free condition (open circles) and mean relative responses per reinforcement in the restrained condition (closed circles) as a function of DRL value. Each point is the mean of the last five days of that condition. The last five days under the longest session length were used for DRL 15-sec and DRL 10-sec. Proportions greater than 0.50 indicate the degree to which reinforcement rate was higher in the free condition, or responses per reinforcer were higher in the restrained condition.

same number of reinforcements under both conditions. The reinforcement rates did not accurately reflect the differences in response rates shown in Figure 4 under DRL 0-sec because very short IRTs did not reliably operate the feeder due to mechanical limitations. All birds, except 262, showed small increases in relative reinforcement rate as the DRL value was increased up to a point, where there was a large increase in relative reinforcement rate. This large increase occurred at DRL 10-sec for Birds 260 and 263, and at DRL 5-sec for Bird 261; these are the same DRL values that resulted in an increase in response rate under the restrained condition. As the DRL value was increased beyond this point, the relative reinforcement rates decreased. Bird 262 showed a large increase in relative reinforcement rate under DRL 3-sec with no systematic changes as DRL value was further increased.

In order to compare responses per reinforcement in the free and restrained conditions, a relative measure was computed by dividing the mean number of responses per reinforcement obtained under a DRL value in the restrained condition by the sum of the mean responses per reinforcement obtained under that DRL value in the free condition plus the mean responses per reinforcement obtained under that DRL value in the restrained condition. This statistic, relative responses per reinforcement in the restrained condition, is presented in Figure 5 as a function of DRL value (closed circles, left side ordinate). The relative responses per reinforcement measure at DRL 0-sec is plotted for continuity. The relative responses per reinforcement was close to 0.5 at low DRL values for all birds except 262. As the DRL value was increased, the relative responses per reinforcement increased slowly, up to a point where there was a sharp increase in the function to 0.90 or higher. This increase occurred at DRL 10-sec for Birds 260 and 263, at DRL 5-sec for Bird 261, and at DRL 3-sec for Bird 262.

At the beginning of extinction, the restrained birds' response rates were higher than the rates of the birds in the free condition (30 and 29 *versus* 16 and 9 responses per minute). By the end of the second day of extinction there was no difference between the restrained and the free conditions. The response rates of all birds were below five re-

sponses per minute by the end of the second day of extinction and were below one response per minute by the end of the fourth day of extinction.

## DISCUSSION

The manipulation of physical restraint interacted with DRL value for the dependent variables of response rate, reinforcement rate, and responses per reinforcement. The magnitude of the effect was zero or near zero under the DRL 0-sec schedule. As the DRL value was increased, a sharp change in behavior occurred at some DRL value. This value varied among subjects, but was the same for all dependent variables within a subject. Other changes in DRL value resulted in relatively small changes in the magnitude of the effect of physical restraint. All birds except Bird 262 showed little effect of restraint at one or more DRL values greater than zero. Possibly Bird 262 would have shown little effect of restraint under some DRL value between 0 and 3 sec if that region had been sampled.

Three lines of evidence indicate that the effect of restraint was not due simply to a high operant level in the restraint. First, during adaptation, none of the birds pecked the key. Second, the effect of restraint appeared as an increase in rate of responding as a function of an increase in DRL value in what was otherwise a monotonically decreasing function. In the free condition, the same change in DRL value resulted in a decrease in response rate. Third, the difference in response rate between the restrained and free birds disappeared quickly during extinction. A comparison of the restrained and free birds during the first exposure to DRL 15-sec shows that physical restraint is not a simple performance variable, like deprivation. The response rates of the restrained birds increased as a function of practice, while the response rates of the free birds decreased or remained the same.

The condition of physical restraint is complex, involving several components; logically, any of these components could have produced the effects. If the effects of physical restraint are ascribed to the impossibility of gross body movement rather than some other component, such as the pressure of the restraint on the

birds' wings, then the conclusion is that collateral behavior is necessary for low response rates and high reinforcement rates under the DRL schedule, at least when the DRL value is not small. This conclusion goes beyond that of previous investigators (e.g., Laties *et al.*, 1969; Segal and Holloway, 1963; Stein and Landis, 1973) that collateral behavior plays an important role in the DRL performance of some subjects. This is consistent with Skinner (1950), who viewed the effect of differential reinforcement of long latencies as being due to the establishment of preliminary behavior "that postpones the response to the key until the proper time". The same conclusion was reached by Schwartz and Williams (1971) after examining the function of collateral behavior under a discrete-trials version of the DRL schedule.

The role of the collateral behavior is not clear. The restrained birds could move their heads and make slight body movements. These movements, which are collateral to key pecking, did not serve to lower response rates to the extent of the movements in the free condition. This does not indicate that these movements are completely ineffective. Perhaps if the birds were completely immobile, except for the key-peck response, the restraint would produce an effect at lower DRL values. The data do not imply that a subject must be continuously active during the IRT in order to have a low response rate and a high reinforcement rate under the DRL schedule; it simply means that some collateral behavior must occur between responses and, perhaps, the form or amount of collateral behavior necessary to be effective depends on the DRL value. Herrnstein (1970) suggested that even simple schedules may be viewed as concurrent schedules where the other responses are unknown. This analysis assigns collateral behavior the function of competing behavior, rather than the discriminative function that collateral behavior is assigned when the collateral behavior is viewed as part of a chain with the key peck as the terminal component.

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