EFFECTS OF EFFORT ON RESPONSE RATE¹

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Pigeons were trained to peck for food reinforcement, and the minimum effective force for a peck was varied. In a single-key situation, the response rate was unaffected up to a certain force value, beyond which increments caused a proportional decrement in response rate. Transient enhancement and suppression effects were observed following a change in the force requirement. A change from a high force requirement to a low force requirement resulted in a temporary enhancement of response rate above the stable performance level, whereas a change from a low to a high requirement produced a temporary suppression of the rate below the stable rate. In a two-key situation, the response rate on a key with a given force remained unaffected by the force requirement on the other key. When the rate of response was plotted against the required force, the resultant function was remarkably similar to that obtained from the single-key experiment. When the rates of reinforcement on the two keys differed, the decrement in response rate produced by an increase in the force requirement was proportionally greater on the key with the lower rate of reinforcement.

Skinner (1938) reported a series of experiments in which the force required to operate a lever was varied and responses were differentially reinforced with respect to their intensity. He noted that when the force requirement was increased, the mean intensity of responses immediately increased, although he found no evidence for accompanying changes in the response rate. However, the range of force thus explored by Skinner was small, and his analysis of the findings was centered on the pattern of force emission during conditioning and extinction. Except for a few studies dealing with the rate of extinction (*e.g.*, Mowrer and Jones, 1943), force, not rate of response, was usually treated as a dependent variable. Attempts have been made previously to record the magnitude of force exerted during the process of conditioning and extinction by the rat (Trotter, 1956; Notterman, 1958) and during generalization along the continuum of wave-length by the pigeon (Cole, 1964).

The experiments reported here were designed to investigate the effects of various response force requirements on the response rate of pigeons. The Ss were trained to respond for food reinforcement, and the response force requirement was varied systematically.

EXPERIMENT I

Subjects. Four male White Carneaux pigeons, experimentally naive, were maintained at 80% of their free-feeding body weights throughout the experiment.

Apparatus. Aside from the special response-key, the apparatus was the standard experimental chamber, as described by Ferster and Skinner (1957). An extension spring, the tension of which could be adjusted, was mounted on the response-key so that the required force could be manipulated (see Fig. 1). A constant displacement of the Plexiglass operated the response-key, and a screw locknut on the bottom of the response-key limited the excursion of the Plexiglass. The required force was calibrated by a Chatillon Model DPP push/pull gauge mounted on a specially designed test stand which permitted the gauge to be pushed slowly forward by turning a knob. The calibration was rechecked once a week. Each peck of at least minimum force operated a relay in the chamber, providing S with auditory feed-

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back for effective responses. A continuous white noise was delivered during experimental sessions to mask the extraneous noise of the laboratory. The chamber was illuminated by a white light bulb, and, except when the magazine was operated, the response-key was trans-illuminated by two 7-w red light bulbs.

Fig. 1. A schematic view of the response-key.

Procedure. All *Ss* were trained to peck the response-key when it was set at a requirement of at least 25 g of force (25-g key). At first, each effective peck operated the magazine for 4 sec, but, after a few sessions, effective pecks were reinforced on a variable interval schedule with an average interval of 1 min (VI 1). Daily sessions were terminated after 50 reinforcements. When the response rates of all *Ss* seemed steady, the tension of the spring was increased, making the required force 100 g (100-g key). A relay click accompanying each effective peck was continuously available, and served as a discriminative stimulus to the *S* regarding the changed force requirement. After two weeks of daily sessions, the tension of the spring was changed to a required force of 150 g. Thereafter, various required forces, ranging from 25 to 300 g in steps of 25 g up to 100 g and 50 g beyond 100 g, were imposed randomly. The order of changes from one force value of the response-key to another was: 25-100-150-50-200-250-75-25-75-100-300-25-150. The *Ss* had a given value of force for 8 to 21 sessions, depending on the speed with which stability in performance was attained. For the 50-g key, *Ss* were exposed for only four sessions due to an apparatus failure.

Results

In general, an increment in the required key-force beyond a certain critical level caused a proportionate decrement in response rate, but the response rates below the critical level were fairly constant for the different force requirement. The highest level of force requirement at which the response rate is unaffected is referred to as the "critical force value". The points plotted in Fig. 2 were obtained by averaging the response rates of the final three sessions at each force value. The data for the 50-g value were not included in Fig. 2, since it received only four sessions due to an apparatus failure. For S-433 all increments in force requirement caused a proportionate decrement in the response rate; for S-432 the response rates were fairly constant for the force requirements up to 250 g. The general shape of the function for S-431 and S-434 lies between these two extreme cases: a horizontal line and a descending line intersect at the critical force value.

Figure 3 shows the average response rates of the four *Ss* at the various required forces. One of the justifications for combining data from different *Ss* can be sought from the ob-

Fig. 2. The response rate as a function of force requirement. Points are obtained by averaging the last three sessions' response rates at each required force.

Fig. 3. The averaged response rate as a function of force requirement. Points are obtained by averaging the four individual Ss' performances, plotted in Fig. 2.

servation that the basic feature of the averaged function is remarkably similar to those obtained from Exp II and III (*cf.* Fig. 7 and 8). As it will be seen later, the group function is also found useful in predicting the group data in Exp II. Although some of the subtle features that can be seen in individual functions, such as the critical force value, are distorted by averaging, simplicity and utility are obtained. When the averaged data are plotted, the function appears to be a straight line with a negative slope.

The effect of change in the required force is well reflected in the initial few sessions following the change. As a rule, a change from a high force requirement to a low force requirement resulted in a temporary enhancement of response rate above the stable performance rate, while a change from a low to a high requirement produced a temporary suppression of the rate below the stable rate. The magnitude of these effects, illustrated in Fig. 4, seems to be a joint function of the previous force requirement and the new force requirement. The sessions are divided into blocks of seven, and the average response rates of successive blocks were again averaged across

Fig. 5. Transient enhancement and suppression effects. The average response rates of the initial three sessions following changes in force requirement are represented by open circles. The numbers accompanying open circles denote the previous force requirement. The filled circles denote the average terminal response rates at the force requirement shown on the abscissa.

the Ss. The enhanced initial rate, when the change was from a high to low force requirement, gradually subsided and reached the stable level. Similarly, a response rate initially suppressed due to an increase in the force requirement slowly rose and approached the stable level.

The enhancement and suppression effects are summarized in Fig. 5. The initial three sessions' response rates, following each change in force requirement, are indicated with white circles along with the values of previous force requirement. The black circles are the average terminal response rates, shown in Fig. 3. For example, when the force requirement was changed from 250 g to 75 g, the average response rate for the initial three sessions was approximately 84 per min, and the enhanced response rate gradually declined to the base-

Fig. 4. Gradual stabilization of the response rate following changes in force requirement. The sessions on a given required force were divided into blocks of seven, and the response rates in each block, averaged across the Ss, are plotted against successive blocks. The numbers denote the values of force requirement in grams.

line response rate, which was about 58 per min. Likewise, when the force requirement was changed from 25 g to 100 g, the initial response rate was suppressed to 24 per min, and by the end of the 15th session the response rate had recovered from the initial suppression, to reach 52 per min.

EXPERIMENT II

Subjects and apparatus. Four White Carneaux pigeons, two of which had previous experience with a wide variety of experiments, and two naive were maintained at 80% of their free-feeding weights throughout the experiment. The arrangement of the experimental chamber was identical to the one used in Exp I except that there were two response-keys. Force on each of the response-keys could again be adjusted by manipulating a spring. Both keys were transilluminated by red light bulbs of 7-w.

Procedure. Following preliminary training on a continuous reinforcement schedule, Ss were placed on a concurrent schedule of reinforcement, the required force for both keys at 25 g. Pecks on either of the two keys were reinforced with 4 sec of food on a VI schedule with an average interval of 1 min. Two independent programmers arranged reinforcements on the two keys, with the restriction that the switch from one key to another prevented reinforcement for 1 sec (Conc VI 1 VI 1 COD 1"). Daily sessions were terminated after 50 reinforcements. After three weeks of exposure to 25-g keys, during which the relative rate of responses on each key became approximately equal, the required force on one key was increased to 75 g, leaving the force requirement on the other key the same (75:25). With the 75:25 combination, 35 sessions were imposed. The tension of the springs was then changed, making the required forces on the right and left response-keys 150 and 75 g, respectively (150:75). With the subsequent changes, the combinations of key forces explored in this study were: 25:25, 75:25, 150:25, 150:75, 200:100, 50:100, and 50:150. At each combination, Ss received 28 to 35 sessions.

Results

The rate of response on a key was found to be independent of the required force on the other key. For example, the number of re-

sponses emitted on the 150-g key remained approximately constant, even when the number of responses emitted on the other key increased or decreased with changes in its force requirement. Figure 6 shows the number of responses emitted at a given required force, averaged across the last three sessions, when

Fig. 6. The number of responses emitted at a given required force, averaged across the last three sessions, when the force requirement on the other key varied. For example, the uppermost Figure shows the number of responses emitted on 25-g key by each of the four Ss when the required forces on the other key were 75 and 150 g. Note that the numbers of responses emitted on one required force-key is unaffected by changes in the force requirement on the other key.

the force requirement on the other key varied. If there had been some sort of "contrast" effect, more responses should have been emitted on the 25-g key when the force requirement on the other key was 150 g than when it was 75 g. No such trend is indicated. The number of responses emitted at each required force was unaffected by the required force on the other key. The ordinate of Fig. 6 is the number, rather than rate, of responses. Since session time was nearly constant, division of the ordinate by 28 would give close to the rate per minute.

Since no contrast effect was observed, it is reasonable to plot the rate of response against the required force, as in Fig. 2 and 3. The data plotted in Fig. 7 were obtained by averaging the last three sessions of all Ss' response rates. It is noteworthy that the function observed in Fig. 7 is almost identical to that of Fig. 3. As in Fig. 3, the plotted points fall on a straight line with a negative slope. For comparison, the function obtained from four different Ss with a single response-key (Exp I) is reproduced in Fig. 7 by a dotted line. The dotted line constitutes the same data points used in Fig. 3. The response rate of the Ss in Exp I is higher than that of the Ss in Exp II. This, of course, is not unexpected, since the schedule of reinforcement in Exp II was Conc VI 1 VI 1, and the response rate was obtained by dividing the number of responses emitted on each response-key by the total session time.

Inasmuch as the contrast effect does not occur in the concurrent situation, it should be possible to predict the distribution of re-

sponses to the two keys, at various required forces, using the result obtained in Exp I. Predictions were calculated from the function in Fig. 2 and are presented in Table 1, along with the observed response distributions. The predicted response distribution was obtained by dividing the number of responses at a given force requirement by the sum of the responses at the two corresponding force requirements in the single-key situation, i.e., $\frac{R_{t1}}{(R_{t2} + R_{t1})}$, where R_{t1} and R_{t2} are the total responses emitted at the two given required forces in Exp I. The agreement between the prediction and observation is surprisingly good. The largest discrepancy is of the order of 4%, with the majority of the observation deviating from the prediction by 1 or 2%.

Table 1

Predicted and observed response distributions on the two concurrent keys when various combinations of force requirements were imposed. Predicted response distributions were calculated from the function obtained in the single-key situation.

Force combination	Predicted response distributions (%)	Observed response distributions (%)
75 : 25	50 : 50	48 : 52
25 : 150	56.5 : 43.5	57 : 43
50 : 100	52 : 48	56 : 44
150 : 75	43.5 : 56.5	44 : 56
200 : 150	46.5 : 53.5	48 : 52
200 : 100	43 : 57	46 : 54
50 : 150	56 : 44	60 : 40

EXPERIMENT III

Subjects and apparatus. The Ss and apparatus used in Exp II were employed for this study. The arrangement of the experimental chamber remained unaltered.

Procedure. The schedule of reinforcement was changed from Conc VI 1 VI 1 COD 1" to Conc VI 1 VI 3 COD 1", while the force requirement was the same on both response-keys. The Ss were exposed to a new schedule for 30 sessions, with force required to operate both right and left keys initially 25 g. The force requirement was then changed in the following order: 150, 100, 200, 50, 250, and 300 g. For both keys the force requirement was kept the same. At each level of force requirement, Ss were exposed for 21 to 30 sessions.

Fig. 7. The response rate as a function of required force in the two-key situation (dark line). The force requirement on each of the two keys was varied independently, and the average response rate on a given force-key was plotted against the force requirement. For comparison, the function obtained from the one-key situation, as shown in Fig. 3, is reproduced with a dotted line.

Results

In Fig. 8 the average response rates on the VI 1 component and the VI 3 component are plotted against the force requirement. Again, the shape of the function for both components is as before (*cf.* Fig. 2, 3, and 7). Figures 2, 3, 7, and 8 indicate response rate is a linear function of force requirement. A close inspection of Fig. 8 reveals a general additive effect of force on response rate. The VI 1 and VI 3 functions in Fig. 8 are almost parallel. At the force requirement of 250 g for instance, Ss emitted virtually no responses on the VI 3 component, while the response rate on the VI 1 component was still substantial. If a constant proportion of responses was eliminated for both components, the slope of the VI 1 component would have been steeper than that of the VI 3. No such trend is indicated. It appears that an equal number, rather than an equal proportion, of responses is eliminated from each component due to an increment in the force requirement.

The observation that an equal number, rather than equal proportion, of responses is eliminated from each component in the concurrent situation due to an increment in force requirement poses an important question. It has been repeatedly shown that the relative response distribution on two response-keys closely matches the relative rate of reinforcement (*e.g.*, Herrnstein, 1961). However, when a force requirement is introduced, the simple principle is no longer valid, as shown in Fig. 8 and 9. The two variables appear to interact in such a way that the decrement in response rate due to the increased force requirement is proportionally higher for the key with the

Fig. 8. The response rate as a function of force requirement in the concurrent situation with different schedules of reinforcement. The upper and lower functions represent the response rates on the VI 1 and VI 3 components, respectively.

lower rate of scheduled reinforcement (see Fig. 8).

In Fig. 9, the relative response distribution on the VI 3 component was plotted against the relative rate of reinforcement actually delivered from that key. Points are obtained by averaging the last three sessions' performance at each force value. The rate of reinforcement delivered from each of the two VI components closely matched the rate of scheduled reinforcement, except when the force requirement was extreme. However, the percentage of responses emitted on the VI 3 component decreased as the force requirement for both VI 1 and VI 3 components increased. At the extreme value of force requirement, the response on the VI 3 component was completely suppressed. If an equal proportion of responses was subtracted from each component due to an increment in force requirement, points in Fig. 9 would have been clustered on a given locus.

Fig. 9. The percentage of responses emitted on the VI 3 component as a function of the relative rate of reinforcement delivered from that component. The numbers accompanying points are the values of force requirement on both VI 1 and VI 3 components.

DISCUSSION

The apparatus employed in the present experiment does not show whether the decrement in response rate is due to a higher frequency of unregistered responses, *i.e.*, responses emitted with a force below the required force level. Using rats, Skinner (1938) observed that as the required force value was increased, the relative frequency of the strong responses increased, but unreinforced responses of inadequate force were always present, especially when an extreme value was employed. Some preliminary data obtained by using a more elaborate recording system confirms Skinner's observation and indicates that this factor accounts for part of the decrement. However, the sum of the effective and ineffective responses also decreased when the force requirement was increased. This observation, along with the initial enhancement and suppression effects following a change in force requirement, and the interaction between the force requirement and the rate of reinforcement, indicates that the organism is acutely sensitive to changes in the force requirement.

It is noteworthy that the effect of force requirement on response rate is similar to that of electric shock. In studies of punishment reported by Azrin (1960), response suppression at the initial introduction of shock gradually recovered as the session proceeded. The recovery of the response rate in the presence of shock intensity was complete, but only when the shock intensity was below a critical level. Beyond this level, the terminal, stable response rate decreased proportionately with further increases in shock intensity. Withdrawal of shock, furthermore, produced a temporary enhancement, which gradually subsided. Analogous phenomena are observed in the present study. The similarities between

the effect of electric shock and increased force requirement do not, of course, lead to the conclusion that "effortfulness" is an aversive stimulus. To warrant such a conclusion, it has to be shown that the organism emits responses in order to avoid an effortful situation.

A general inference to be drawn from the present findings is that force interacts with response rate additively, rather than multiplicatively. The additive nature of force on response rate is clearly shown in all experiments reported here. On the surface, the present findings may appear to fit into Hull's (1943) notion of inhibitory aggregate (or total inhibitory potential, I_R) subtracting from reaction potential (sE_R). However, Hull's theory of inhibition involves a number of unspecified relationships, making only qualitative, and not quantitative, confirmation possible.

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