

THE EFFECT OF RESPONSE RATE ON REWARD VALUE IN A SELF-CONTROL TASK

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To understand how effort, defined by number of responses required to obtain a reward, affects reward value, five pigeons were exposed to a self-control task. They chose between two alternatives, 2 s of access to food after a delay of 10 s, and 6 s of access to food after an adjusting delay. The adjusting delay increased or decreased depending on the pigeons' choices. The delay at which the two alternatives were equally chosen defined the indifference point. To determine whether requiring responses during the delay led to more impulsive (smaller-sooner rewards) or self-controlled (larger-later rewards) choices, we varied the number of required pecks during the 10-s delay to the 2-s reinforcer, and assessed how the requirement affected the indifference points. In the High Rate Phase, they had to peck at least 10 times during the delay; in the Low Rate Phase, they could peck at most 5 times during the delay. For four pigeons the indifference point increased with the response requirement; for one pigeon it decreased. The results suggest that, in general, reward value varies inversely with effort.

*Key words:* self-control, response rate, reward value, adjusting-delay procedure, pigeons

Everything else being equal, immediate rewards are preferred to delayed rewards. That is, the present value of a delayed reward is less than that of an immediate reward. The decrease in the present value of a delayed reward is called delayed discounting, and it is usually studied in a self-control task where subjects choose between a smaller-sooner reward and a larger-later reward. Choice of the smaller-sooner reward is described as an impulsive choice, whereas choice of the larger-later reward is described as a self-controlled choice (Rachlin & Green, 1972). To predict choices in this task, it is crucial to identify the discounting function that specifies how the value of a reward decreases with its delay.

To study the discounting function, Mazur (1987) developed an adjusting-delay procedure. The subject chooses between a standard alternative, for which delay and amount of food are held constant, and an adjusting alternative, for

which amount of food is held constant while delay is changed systematically depending on the subject's choices. The adjusting delay decreases whenever the subject chooses the standard alternative, and increases whenever the subject chooses the adjusting alternative. The purpose of these adjustments is to find the adjusting delay at which the subject chooses each alternative equally often—the indifference point. The standard delay is then varied across experimental conditions and several indifference points are obtained, so that the function relating reward value to delay can be determined.

Equation 1 was consistent with Mazur's (1987) results:

$$V = \frac{A}{1 + KD} \quad (1)$$

where  $V$  is the subjective value of an alternative,  $A$  is related to food amount,  $D$  is the delay between choice and food delivery, and  $K$  is a discounting rate parameter. If we conceive of delay to food as a cost associated with the corresponding alternative, Equation 1 states that as the cost of an alternative increases, the subjective value of that alternative decreases hyperbolically.

In addition to delay, Equation 1 has also accounted well for the effects of other cost variables. To illustrate, if the odds against receiving a reward is substituted for  $D$ , Equation 1 describes well how reward value changes with reward probability (probability discounting; Green & Myerson, 2004).

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In everyday life, most rewards are not only delayed or probabilistic, but also depend on some responses, behaviors, or, more generally, effort. For instance, if a student has a deadline to deliver a paper, the time available to write it is fixed. However, the student may choose to expend more effort and receive a higher grade or to expend less effort and receive a lower grade. Similarly, animals may face situations in which they have to choose between a larger prey that requires more effort to catch, and a smaller prey that is easier to catch. Thus, response effort is a behavioral dimension that has important implications outside the laboratory, and therefore it is crucial to understand how it affects behavior.

Mazur's hyperbola (Eq. 1) can also be applied to describe how requiring responses during the delay affects reward value (Grossbard & Mazur, 1986; Mazur, 1986; Mazur & Kralik, 1990). At a more basic level, examining how a response requirement affects reward value (e.g., will it suffice to replace  $D$  in Equation 1 by the response requirement?) would allow us to predict choices between time-based and ratio-based schedules (Mazur, 1986).

Consider a concurrent task in which a pigeon chooses between a fixed-ratio (FR) and a fixed-time (FT) schedule. In the former, the subject has to peck a key multiple times to obtain a reward; in the latter, the subject may, but does not have to, peck the key to obtain a reward. But if, as Killeen (1969) and Neuringer and Schneider (1968) suggested, what determines behavior in FR schedules is not the required number of pecks *per se* but the delay to food, then, when the two alternatives have the same delay, the subject should be indifferent between them. Some results, using fixed-interval (FI) instead of FR schedules in concurrent-chains procedures, are consistent with this hypothesis, for they have found no significant differences in preference between FT schedules and FI schedules with the same delay to reward (Davison, Alsop, & Denison, 1988; Neuringer, 1969).

In contrast, other experiments using a discrete-trial adjusting-delay procedure showed that requiring responses alters the value of a reinforcer. Grossbard and Mazur (1986) compared FR schedules with FT schedules, with parameters chosen to match the average times to complete the FR schedule. They found that pigeons generally preferred time schedules to

ratio schedules. However, this result is difficult to interpret for two reasons. First, there was substantial variability among subjects and individual results were often inconsistent across phases. And second, because variations in response rate in the FR schedule brought about variations in the time to complete the FR schedule, the comparison in their study was, in fact, between a variable delay with a response requirement and a fixed delay without a response requirement. Given that animals seem to prefer variable to fixed delays to food when the average time to food is the same (Herrnstein, 1964), the effect of the response requirement in Grossbard and Mazur's study may have been confounded with the effect of the variability in the delays to food.

To control for variability in the FR completion times, Mazur and Kralik (1990) used a variable-time (VT) schedule instead of an FT schedule. For each pigeon, the VT schedule intervals were chosen to match the completion times in the FR schedule. With equal times to food, all pigeons showed a preference for the VT schedule, thus suggesting that requiring responses to obtain a reward devalues the reward.

This conclusion would be stronger were it not for the fact that two other procedural features, in addition to the response requirement, differed between the time and ratio alternatives. First, in the time schedules food was not necessarily contiguous with a response, whereas in the ratio schedules food was always contiguous with a response. Thus, the animal's choices were between reinforcers contiguous with a response and reinforcers not contiguous with a response (cf. Osborne, 1977). Second, and perhaps more important, the schedules differed also in the stimuli presented between choice and food: In the ratio schedules, a colored key was lit so that the pigeon could peck at it; in the time schedules, a colored houselight was lit. Because food always followed when the houselight was turned on, the houselight could have served as a conditioned reinforcer (see Mazur, 1995). It is not clear whether these two procedural differences could have enhanced preference for the time schedules.

The present experiment aimed to provide additional data on the effect of response effort on the value of a reinforcer. The main question was whether pigeons would prefer a reinforcer delivered after few responses to a reinforcer

delivered after many responses. In order to compare the present experiment with previous studies, we used the adjusting-delay procedure used by Mazur and Kralik (1990). Across phases, we manipulated the responses required during the delay, and examined how the requirement affected the indifference point. Importantly, we kept constant the delay between choice and food. Moreover, to control the potential confounds mentioned above and to ensure that the two alternatives differed only in the response requirement, a) all reinforcers were not necessarily contiguous with a response, and b) the stimuli present during the delays were the same in both alternatives.

The experiment included three phases: Baseline, High Rate, and Low Rate. During baseline, the standard alternative was an FT 10 s followed by a 2-s reinforcer, and the adjusting alternative was an FT followed by a 6-s reinforcer. The value of 10 s on the standard alternative was chosen because it was long enough to allow response rate manipulation but short enough for the animals to sustain a high response rate in the High Rate Phase and to refrain from pecking in the LR Phase. The other phases differed only in the number of responses required during the standard delay. In the High Rate Phase, at least 10 responses were required during the standard delay; in the Low Rate Phase, a maximum of 5 responses was allowed during the standard delay. We predicted that, if responding during the delay devalues the standard alternative, then, the pigeons would choose more the adjusting alternative. Consequently, due to the adjusting-delay procedure, the adjusting delay would increase, and the indifference point would be higher in the High Rate Phase than in the Low Rate Phase.

## Method

### Subjects

Five pigeons (*Columba livia*) maintained at approximately 80% of their free-feeding weights participated in this experiment. In their home cages water and grit were always available. The colony had a 13h:11h light/dark cycle, with the lights on at 8 am. The room-temperature was set between 20° and 22°Celsius. All pigeons had previous experience with a variety of procedures, including the adjusting-delay procedure.

### Apparatus

Three Lehigh Valley<sup>®</sup> operant boxes for pigeons were used. The boxes were 34 cm high, 35 cm long, and 31 cm wide. Each box was equipped with a ventilation fan that also masked outside noises. The front panel was equipped with three horizontally aligned keys, each 2.5 cm in diameter. The keys were 9 cm apart, center-to-center, and 22.5 cm above the floor (measured from their lowest point). The side keys could be illuminated with red or green hues, and the central key could be illuminated with a white hue. The feeder opening (5 cm high x 6 cm long) was centrally located on the front panel, 8.5 cm above the floor. When activated, the food hopper was illuminated with a 1.1-W light. On the opposite panel, centrally located and 30 cm above the floor, a 2.8-W houselight illuminated the box.

A personal computer with a custom Visual Basic 2008 program controlled the events and recorded data via Whisker.

### General Procedure

Pigeons chose between a standard alternative and an adjusting alternative. Throughout the experiment the standard alternative consisted of an FT 10 s followed by 2 s of access to food; the adjusting alternative consisted of an FT schedule with an adjusting parameter followed by 6 s of access to food. We refer to the two delays to food imposed by the FT schedules as "standard delay" and "adjusting delay", respectively. For three pigeons (P8201, PG15 and P928) the standard alternative was signaled by a green hue and the adjusting alternative was signaled by a red hue; for the remaining pigeons (P366 and P726) the color mapping was reversed.

The experiment comprised different phases: Baseline, Low Rate (LR) and High Rate (HR). During baseline, the first phase, no responses were required during both delays to food. The LR and HR phases differed only in the number of responses required during the 10-s standard delay. In the LR Phase, at most 5 pecks were allowed during the delay (i.e., the highest average rate the pigeon could peck at the key was 0.5 pecks/s). In the HR Phase, at least 10 pecks were required during the delay (i.e., the lowest average rate the pigeon could peck at the key was 1 peck/s). No responses were ever required during the adjusting delay.

The first phase was the Baseline Phase. Which phase followed the baseline depended on the pigeons' behavior during the last three sessions of baseline. If the average response rate in the standard delay was less than 1 peck/s, the next phase was HR; if the average response rate was greater than 1 peck/s the next phase was LR. This decision ensured that a noticeable change in response rate during the standard delay would take place between phases. Thus, the experiment could follow an ABCBC design or an ACBCB design, in which Phase A was the Baseline Phase, Phase B was the HR Phase and Phase C was the LR Phase.

Each phase included training sessions during which the number of required pecks gradually decreased (in the LR Phase) or increased (in the HR Phase). These sessions continued until the pigeons met the response requirement reliably.

### Baseline Phase

**Training Condition.** During training sessions, the delay on the adjusting alternative remained constant, and the pigeons were exposed to only one alternative on each trial.

A trial began with the illumination of the white center key. A peck on this key—required to place the pigeon equidistant from the side keys at the moment of choice—turned the keylight off and illuminated one of the side keys with a flashing light (250 ms on, 250 ms off) of either a red or a green hue. The left-right location of the illuminated key varied pseudorandomly across trials. The first peck on the flashing key changed its illumination to a steady light and initiated the delay. If the illuminated key represented the standard alternative, then after a 10-s delay the keylight was turned off and the feeder was activated for 2 s. If the illuminated key represented the adjusting alternative, then after a 10-s delay the keylight was turned off and the feeder was activated for 6 s. After reinforcement, an intertrial interval (ITI) began with only the houselight on. The duration of the ITI varied such that the total trial duration equaled 70 s. There was a 10-s limited hold to peck the center key and a 15-s limited hold to peck the side keys. If the pigeon failed to peck a key within the limited hold periods, the key was turned off,

the ITI began, and the trial was repeated until it ended with reinforcement.

Training sessions consisted of four blocks of 11 trials each, for a total of 44 trials. Within each block, five trials presented the standard alternative, five presented the adjusting alternative, and on one trial the peck on the center key (required to start the trial) was immediately reinforced with 4 s of access to food (data from these trials were excluded from analysis). The order of the 11 trials within each block was random. Each session ended after either the 44 trials were completed or 70 min had elapsed, whichever came first.

Training continued for a minimum of four sessions and until at least 85% of all trials (including repetitions—trials without a response within the limited hold periods) were reinforced for three consecutive sessions.

**Adjusting-Delay Condition.** Each session consisted of 44 trials, divided into four blocks of 11 trials each. Within each block, the first two trials were forced-choice trials (equal to training trials described above), eight were free-choice trials and on the remaining trial the first peck on the center key was reinforced.

The sequence of events on a free-choice trial was identical to the forced-choice trials, except that after a peck on the center key, both side keys turned on with flashing lights, one red and the other green. The first peck on one of the side keys changed its illumination from flashing to steady, turned off the other key, and initiated the delay. On the adjusting alternative trials, long latencies and long delays could make the interval from the beginning of a trial to the end of reinforcement longer than 70 s; in that case the ITI was set at 15 s.

The adjusting delay remained constant within a block but changed across blocks according to the pigeon's choices on the eight free-choice trials of the previous block. If the pigeon chose the adjusting key on fewer than three trials, the adjusting delay decreased by 1 s on the next block; if the pigeon chose the adjusting key on more than five trials, the adjusting delay increased by 1 s on the next block; and if the pigeon chose the adjusting alternative on three, four or five trials, the adjusting delay did not change.

On the first block of trials of the first session, the adjusting delay was set at 10 s. In subsequent sessions, the adjusting delay on the first block of

trials was computed from the choices made during the last block of the previous session.

The adjusting-delay sessions continued for at least 10 sessions and until three stability criteria were met: a) the highest or the lowest adjusting-delay session mean did not occur in the last five sessions; b) the mean adjusting delay of the last five sessions was neither the highest nor the lowest mean of five consecutive sessions; and c) the mean adjusting delay of the last five sessions did not differ by more than 10% from the previous five sessions.

### High Rate (HR) Phase

**Training Condition.** In the HR training sessions, the pigeons were trained to peck at a high average rate (at least 1 peck/s) during the standard delay. To increase response rate, pigeons were trained to respond under an FR 20 schedule in the standard alternative. That is, after the choice peck, the pigeon had to peck 20 times to obtain the reinforcer. When the first 10 responses were emitted in less than 10 s on at least 80% of the trials, the FR 20 schedule was replaced by an FT 10 s schedule with at least five responses required during the delay. This arrangement exposed the pigeon to a situation in which responses were required, but, in contrast with an FR schedule, responses were not necessarily followed by food. When at least 85% of all trials in a session ended with reinforcement, the number of required pecks increased from 5 to 10 responses. If the pigeon failed to meet the response requirement the trial ended without food and was repeated.

The adjusting delay remained constant throughout training and it was equal to the indifference point of the previous condition. The stability criteria were the same as in the baseline condition.

**Adjusting-Delay Condition.** The adjusting-delay condition of the HR Phase was identical to the adjusting-delay condition of the baseline, with the exception that, to receive the 2-s reinforcer the pigeons had to peck at least 10 times during the standard delay.

### Low Rate (LR) Phase

**Training Condition.** In these sessions, the pigeons were trained to peck at a low average rate (at most 0.5 pecks/s) during the standard delay. In each session, an upper limit on the total number of responses during the 10-s

standard delay was imposed, and this limit decreased progressively across sessions according to a modified percentile reinforcement schedule. The 60th percentile of the total responses emitted during the standard delays of the previous session was determined. The percentile defined the upper response limit for the next session. If the response limit was higher than the previous session, the limit remained the same; if it was lower, the limit was decreased. The percentile schedule was in effect until the upper limit equaled five responses. If a pigeon exceeded the response limit, the trial was immediately cancelled and repeated.

As in the HR training condition, the adjusting delay remained constant throughout training and it was equal to the indifference point of the previous condition; the stability criteria also remained the same as in baseline.

Pigeon P726 failed to meet the criteria after 53 sessions. Therefore, the upper limit was set to nine responses instead of five.

**Adjusting-Delay Condition.** The adjusting-delay condition of the LR Phase was identical to the adjusting-delay condition of the baseline, with the exception that, to receive the 2-s reinforcer pigeons could not peck more than five times (nine for pigeon P726) during the standard delay.

## Results

Due to unpredictable construction work in the laboratory, we were forced to end the experiment when only three pigeons had completed all five experimental phases (baseline, two HR phases and two LR phases); the other two pigeons (P366 and P726) completed three phases (baseline, one HR Phase and one LR Phase).

During the last three baseline sessions, four pigeons (except P726) pecked the standard key at an average rate equal to or smaller than 1 peck/s; hence, these pigeons started with the HR Phase (ABCBC for P8201, P928, PG15; ABC for P366). Pigeon P726 pecked at an average rate greater than 1 peck/s and therefore it started with the LR Phase (ACB).

In the HR phases, all pigeons learned to peck at a minimum average rate of 1 peck/s. In the LR phases, all but one pigeon learned to peck at a maximum average rate of 0.5 pecks/s. The exception was Pigeon P726 for whom the maximum in the LR Phase was set to 0.9 pecks/s.

During the training conditions of the Baseline, HR, and LR phases (see Procedure above) the pigeons met the stability criteria after an average of, respectively, 4.4 sessions (range: 4–5), 14.3 sessions (range: 7–41), and 22.1 sessions (range: 6–80). During the adjusting-delay conditions of the Baseline, HR, and LR phases, pigeons met the stability criteria after an average of, respectively, 16.2 sessions (range: 14–21), 19.3 sessions (range: 11–29), and 17.0 sessions (range: 13–22).

In the adjusting-delay conditions, the average of the adjusting delay during the last five sessions defined the indifference point. Figure 1 presents the indifference points obtained in each phase and for each pigeon (exact values are shown in the Appendix). The left panel presents the results of the three pigeons that completed the five phases, and the right panel presents the results of the two pigeons that completed only three phases, as well as the group mean results.

The indifference points of the HR and LR phases are the most relevant because they address the central question of the study—Does response rate during the delay to food affect the value of the alternative? If a high

response rate devalues an alternative more than a low response rate, then the standard alternative in the HR Phase should have less value than the standard alternative in the LR Phase. Consequently, because a lower value of the standard alternative means a stronger preference for the adjusting alternative and, therefore, a longer adjusting delay, the indifference points should be higher in the HR than in the LR phases. Equivalently, the higher the indifference point, the lower the value of the standard alternative.

With the exception of one pigeon, all indifference points in the HR Phase were higher than the indifference points in the LR Phase. Grouping data for repeated phases and averaging across subjects yields a mean indifference point of 27 s in the LR Phase and 36 s in the HR Phase. This result indicates a preference for the standard alternative when pigeons had to peck less during the delay to food. The exception, PG15, revealed the opposite pattern: The indifference points were consistently higher in the LR Phase, indicating a preference for the standard alternative when the pigeon had to peck more (HR) during the delay to food.

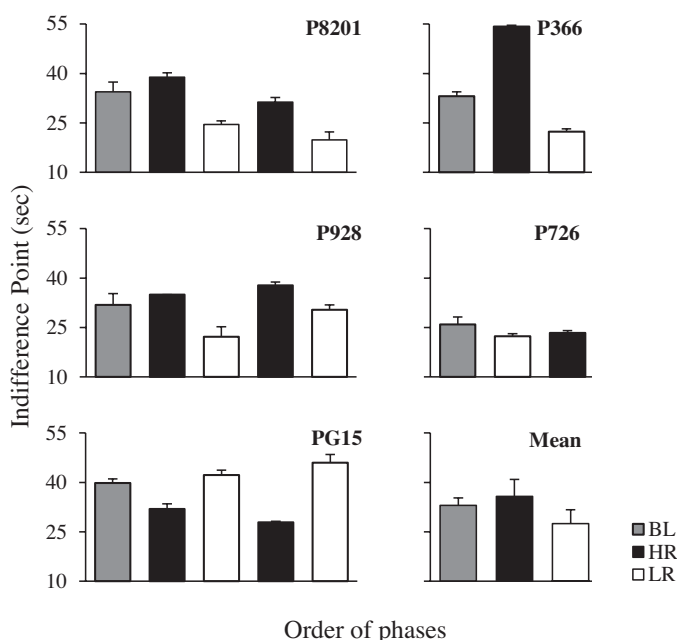


Fig. 1. Indifference points (in seconds), for each pigeon in each phase. BL, HR, and LR denote the Baseline (gray bars), High Rate (black bars), and Low Rate (white bars) phases, respectively. The error bars are the standard deviation in individual graphs and the standard error of the mean in the group mean.

The difference in the indifference points between the HR and LR phases was smallest for pigeon P726. Note, however, that the procedure was different for this bird. First, the order of phases was different; second, the maximum response rate in the LR Phase was set to 0.9 pecks/s and not at 0.5 pecks/s as for the remaining pigeons. The smaller difference in response requirements between phases may explain the smaller difference in the LR and HR indifference points.

Intuitively, the response requirement during the HR Phase seems more difficult to learn and maintain than the response requirement during the LR Phase. To assess whether this was the case, we examined the number of sessions of training in each phase and found that a paired-samples *t*-test did not yield a statistically significant difference between the LR and HR phases,  $t(4) = 0.78$ ,  $p = .24$  (individual number of sessions are shown in the Appendix).

Although there were no significant differences between phases in learning the response requirement, it is possible that there were differences in maintaining the response requirement. These differences could be revealed by the proportion of nonreinforced trials due to failure to meet the response requirement. These differences are potentially important and to illustrate the point assume that the number of nonreinforced trials is higher during the HR than the LR phases. This difference could bias the subjects to choose the adjusting alternative more in the HR than in the LR phases because in the adjusting alternative there was no requirement during the delay and, as a result, regardless of the pigeon's behavior, the reinforcer was always delivered. However, a paired-samples *t*-test found no statistically significant difference in the proportion of nonreinforced trials between the LR and HR phases,  $t(4) = 0.44$ ,  $p = .34$ . The proportion of nonreinforced trials in the HR phase ranged from 3 to 11% (mean = 5%) and in the LR phase ranged from 2 to 8% (mean = 5%). Thus, differences in the proportion of nonreinforced trials do not account for the higher average indifference points in the HR Phase.

The behavioral requirements during the standard delay were different in different phases. On the one hand, during the baseline there were no constraints on response rate. On the other hand, in both LR and HR phases

response rate was constrained, and the contingencies forced the birds to behave differently from the baseline. If we assume that constraining behavior is aversive, we would expect the baseline standard alternative to be the least aversive, and therefore the most preferred. Thus, if the standard alternative during the baseline was the most preferred, its indifference point should be the smallest. However, no pigeon had the smallest indifference points at baseline. In fact, Figure 1 shows that the indifference point in baseline was generally in between the LR and HR indifference points.

Possibly the indifference points are related to response rate during the standard delay. If this is true, and given that the baseline indifference point had an intermediate value relative to the other phases, we would expect the baseline response rate also to be intermediate to the other phases.

Figure 2 shows the indifference points plotted as a function of response rate during the standard delay for each subject. For repeated phases data were grouped. As expected, for the majority of the pigeons the response rate during the baseline (grey data points) was between the response rates during the other phases. The exception was pigeon P726 who showed the highest response rate in baseline. Although there was substantial variability between subjects, there seems to be a trend in the data, with indifference points increasing with response rate during the standard delay. However, although response rate during the HR Phase was almost twice as high as the response rate during the baseline (cf. horizontal placement of the baseline and HR points in Fig. 2), the difference between the indifference points in these two phases was usually small and inconsistent across birds (cf. vertical placement of the baseline and HR points in Fig. 2). The small number of birds and the substantial variability in the data preclude any stronger conclusions.

Figure 2 suggests that the value of a reinforcer might be influenced by the number of responses during the delay, whether or not these responses are imposed. For the majority of the pigeons, the higher the response rate the higher the indifference point, that is, the less value the standard reinforcer has. However, if pecking during the delay devalues food, we should expect pigeons not to peck during the baseline, when no responses were required. Yet,

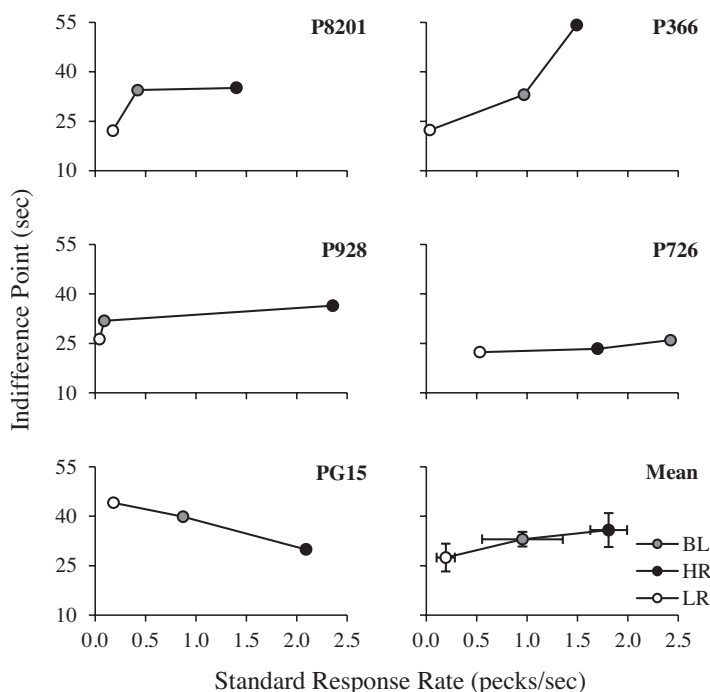


Fig. 2. Indifference points (in seconds) as a function of response rate (pecks per second) during the standard delay in the last five sessions of each adjusting-delay condition. BL, HR, and LR denote the Baseline (gray circles), High Rate (black circles), and Low Rate (white circles) phases, respectively. For pigeons P8201, P928 and PG15 the results were averaged across replications. The group means are also shown. The vertical and horizontal bars indicate the standard error of the mean for each phase.

they pecked at an average rate of 0.95 pecks/s during the standard delay.

Additionally, the pigeons were never required to peck during the adjusting delays. To see how they behaved during the adjusting delays, we computed the average response rate during the last five sessions of the adjusting delay conditions. These averages in pecks/s equaled 0.25 in the LR Phase, 0.30 in the baseline, and 0.29 in the HR Phase. So, in contrast with the standard delay in the baseline, pigeons rarely pecked during the adjusting delays.

In this experiment we manipulated the response rate requirement during the standard delay and observed that the effect of our independent variable varied greatly across birds. Part of this variability might be explained by the fact that the independent variable was flexible, in the sense that pigeons could vary response rate within a range: In the LR Phase pigeons could peck at any rate between 0 and 0.5 pecks/s on average, and on the HR Phase pigeons could peck at any rate greater

than 1 peck/s on average. Moreover, there were no restrictions on when the pecks occurred during the delay. They could be, for instance, concentrated at the beginning, middle, or end of the delay, or evenly distributed across the delay.

Figure 3 shows, for each pigeon, the average response rate during the standard delay. In the LR Phase, the response rate curve was either close to 0 or decreased during the delay (see white circles). In the HR Phase (black circles) response rate usually increased until the middle of the delay and then gradually decreased. Pigeon PG15 presented a different pattern, an S-shaped curve with a low response rate at the beginning of the delay and then a gradual increase until the end of the delay. Finally, during baseline (gray circles), the response pattern differed significantly across birds. Pigeon P8201 decreased response rate during the delay; pigeons P366 and P726 showed inverted U curves; P928 rarely pecked the key; and pigeon PG15 showed a decreasing curve.



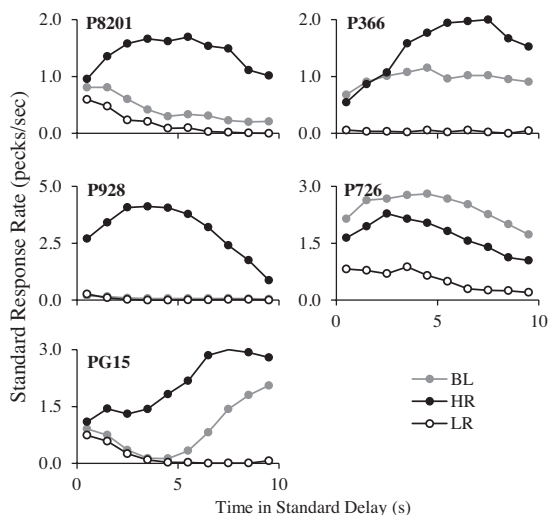


Fig. 3. Average response rate during the standard delay in the last five sessions of each adjusting-delay condition. For pigeons P8201, P928 and PG15 the results were averaged across replications. BL, HR, and LR denote the Baseline (gray circles), High Rate (black circles), and Low Rate (white circles) phases, respectively.

## Discussion

The main purpose of the present experiment was to examine, in a typical self-control task, how response effort affected reinforcement value. Previous studies manipulated effort by varying the number of responses required to obtain a reinforcer. However, this manipulation necessarily confounds effort and time, for the more responses are required, the longer the delay to food is. In the present study, we investigated the effect of response effort on value, by manipulating the response rate during the delay to food while maintaining constant the delay length. Moreover, contrary to previous studies (Grossbard & Mazur, 1986; Mazur, 1986; Mazur & Kralik, 1990), a colored key was lit during both the delays that required a high rate of responding and a low rate of responding.

First, we found that the adjusting-delay procedure can be used to produce stable and reliable indifference points when response rate during the delay to food is manipulated. It is important to note that the results were replicable for individual subjects (left panel of Fig. 1). Second, for four out of five pigeons the indifference points increased as the response rate during the standard delay in-

creased. The magnitude of the change in the indifference points was comparable to that obtained by Mazur and Kralik (1990). During the LR Phase, our pigeons pecked 2 times on average during the standard delay and the obtained indifference point averaged 27 s. In the HR Phase, pigeons pecked 18 times on average and the obtained indifference point averaged 36 s. An increase of 16 pecks during the 10-s delay was accompanied by a 33% increase in the indifference point. Mazur and Kralik obtained an increase of 38% in the indifference point from a condition with nearly zero pecks to a condition with 15 pecks during the delay. An increase in the indifference points with an increase in response rate suggests that value decreases with response effort. In the self-control context, this means that the more the subjects respond for the smaller reward, the more they choose the larger reward (i.e., the more they show self-control). And third, we found that the higher indifference points in the HR Phase could not be attributed to a greater difficulty in learning or maintaining the response requirements during the standard delay.

An interesting finding of the present study is that an alternative with behavioral constraints does not have necessarily less value than an alternative without behavioral constraints; it can even have more value. If pigeons prefer less to more pecking, why did they peck during the standard delay in the baseline? The answer may be related to the FT reinforcement schedule. It is well established that pigeons will frequently peck a key even when the delivery of food is independent of the animal's behavior (Brown & Jenkins, 1968; see also Osborne, 1977). Although the average response rate during the baseline standard delay was 0.95 pecks/s, during the adjusting delay the response rate was three times less, 0.30 pecks/s. The fact that the shorter (standard) delay sustained more responding than the longer (adjusting) delay indicates that responding during the baseline standard delay may have been schedule-induced.

For pigeon PG15, the indifference point decreased with response rate, suggesting that, for this pigeon, and in contrast with the remaining ones, value may have increased with response rate. This result challenges the general assumption that animals prefer low-effort to high-effort options. Although self-control studies have typically found a decrease in preference as the cost to obtain a reward

increases (Mitchell, 2003), some studies on simple discrimination tasks have reported a preference for stimuli associated with higher effort (Clement, Feltus, Kaiser, & Zentall, 2000; however, see Vasconcelos, Urcuioli, & Lionello-DeNolf, 2007).

To try to understand the variability among birds, we asked whether something in pigeon PG15's behavior distinguished it from the other birds. In Figure 3, consider the response rate curves and focus on their pattern or shape rather than their absolute values. Interestingly, for PG15 the pattern during the baseline delay was more similar to the HR pattern than to the LR pattern. For the remaining pigeons, either there were no differences in the pattern across phases (P726) or the pattern during the baseline was more similar to the LR pattern than the HR pattern (pigeons P8201, P928 and P366). Thus, it seems that when the response rate pattern differs across phases, the preferred alternative is the one with a pattern most similar to the baseline pattern.

Despite the abovementioned variability, for most pigeons responding at a high response rate during the delay to food devalued that option. How can this finding be accounted for by Equation 1? On the one hand, the numerator, that is, the utility of food,  $A$ , can decrease. On the other hand, the denominator can increase for several reasons. First, reward can devalue more quickly when the animal has to respond during the delay, that is,  $K$  can increase. With this change, Equation 1 predicts that indifference points are a linear function of the variable manipulated in the standard alternative (e.g., response rate in the present experiment). In fact, Mazur's (1986) results were consistent with an increase in  $K$  for more effortful responses. Second, responding at a high rate can alter perception of time. In that case,  $D$  in Equation 1 is not the objective delay but the subjective delay, which is longer when pigeons have to peck (see Zentall & Singer, 2008). One possibility would be to raise  $D$  to a power higher than 1. In this case, curvilinear indifference functions are predicted, and that was indeed what Mazur and Kralik (1990) observed. Even though the present study was not designed to test different discounting equations, its nonlinear results are consistent with those obtained by Mazur and Kralik.

The shortage of studies on effort discounting as compared with studies of delay or probability

discounting can be explained, in part, by the difficulty to answer two questions: a) what is effort and how best to *operationalize* it?, and b) how to disentangle the effects of effort from the effects of delay? Concerning the first question, many studies mention effort without clearly defining what is meant by it. This is problematic because there are different types of effort and their effect on value may be different. In some studies, effort was manipulated by the degree of difficulty of math operations (humans, Botvinick, Huffstetler, & McGuire, 2009; see also Neef, Shade, & Miller, 1994); in others, it was manipulated by the physical force required to squeeze a device for some time (humans, Mitchell, 2003), or to press a heavy lever (rats, Chelonis, Logue, Sheehy, & Mao, 1998); for still others, it was manipulated by the number of responses required to obtain a reward (pigeons, Grossbard & Mazur, 1986; starlings, Aw, Vasconcelos, & Kacelnik, 2011; hypothetical effort in humans, Sugiawaka & Okouchi, 2004). Whether all these types of effort can be measured in a common scale remains to be seen.

With respect to the second question, how to separate the effects of delay and effort, the answer depends on the type of effort. If effort is manipulated by the amount of force required to respond, the time between choice and reward should not be affected by the force required. However, if effort is defined by the number of responses required to obtain a reward, it will tend to covary with the delay to reward.

Conceptual and methodological controversies aside, the most important contributions of the present study are to show that (a) it is possible to manipulate effort by the number of responses while maintaining the delay to the reward constant, (b) the value of a reward appears to decrease with effort in a self-control paradigm, and (c) the indifference points may be one objective way of quantifying effort.

Besides the main results described above, we also found that a given amount of effort may not affect all subjects in the same way. Therefore, prior to manipulating effort, it is important to identify the baseline level of responding for each subject. In applied settings, response effort manipulation can be used to increase desirable behaviors and/or decrease undesirable behaviors (Friman & Poling, 1995). For example, to increase the frequency of self-control choices, it may suffice to decrease the

effort associated with the self-control option below its baseline, or to increase the effort associated with the concurrent options (alternatively, see Dixon & Cummings, 2001). Moreover, it is also important to take into account how effort is introduced to the subject. It is known from the animal literature that generalized exposure to effort can lead to more choices of a larger-high effort option over a smaller-low effort option (Eisenberger, Weier, Masterson, & Theis, 1989; for a review see Eisenberger, 1992). Therefore, taking into account the baseline behavior, individualizing the effort levels, and increasing effort progressively in different contexts may be a possible way of establishing a desired behavior (for more applications of response effort refer to Friman & Poling, 1995). This line of intervention and research is promising and may be worth pursuing.

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Appendix

Table A1

Number of Sessions to Reach Stability in Each Condition for Each Pigeon. For the Adjusting-Delay Conditions, the Indifference Point (in sec) is Shown in Parentheses.

Phases	Condition	Pigeon					Mean
		P8201	PG15	P928	P366	P726	
Baseline	Training	5	4	4	5	4	4
	Adjusting- Delay	15 (34.45)	21 (39.85)	14 (31.85)	17 (33.10)	14 (25.95)	16 (33.04)
High Rate 1	Training	13	10	9	41	9	16
	Adjusting- Delay	26 (38.90)	16 (31.95)	18 (35.00)	29 (54.20)	12 (23.35)	20 (36.68)
Low Rate 1	Training	12	23	10	25	80	30
	Adjusting- Delay	13 (24.50)	16 (42.25)	14 (22.20)	20 (22.35)	15 (22.35)	16 (26.73)
High Rate 2	Training	11	14	7	–	–	11
	Adjusting- Delay	11 (31.35)	24 (27.85)	18 (37.80)	–	–	18 (32.33)
Low Rate 2	Training	10	11	6	–	–	9
	Adjusting- Delay	17 (19.85)	22 (46.00)	19 (30.40)	–	–	19 (32.08)