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Performance in a computerized self-control task by rhesus macaques (*Macaca mulatta*): The combined influence of effort and delay

Theodore A. Evans
Language Research Center

Abstract

The variables of delay and effort have been found to influence self-control predictably and in similar fashion when tested independently, but it is unclear how they influence self-control interactively. In the present study, I tested these 2 variables simultaneously to gain better understanding of their combined influence on self-control. A computerized task was employed in which monkey participants could sequence 1 or more digital images before “cashing-out,” after which they would receive their accumulated rewards. Delay was manipulated by adjusting the speed of the cursor used to select images. Cognitive effort was manipulated by presenting image sets that appeared in either a constant or a randomized configuration. For most monkeys, an interaction was found between the effects of delay and effort on the number of images selected before cashing-out. The results suggest that, when combined, these 2 variables have a complex influence on self-control.

In the natural environment, self-control means enduring certain costs in order to attain a greater goal (Eisenberger, Weier, Masterson, & Theis, 1989). In the laboratory, self-control is most often defined as tolerating a long delay to obtain a greater reward, and impulsivity is defined as avoiding the delay, thereby earning a lesser reward (Rachlin & Green, 1972). However, there are other costs associated with self-control besides long delay, such as increased effort (Mischel, 1974), punishment (Mischel & Grusec, 1967), and low probability of rewards (Rachlin, 1989). In natural situations, self-control probably involves some combination of two or more costs (Eisernberger, Mitchell & Masterson, 1985; Eisenburger & Adornetto, 1986). For example, one might be confronted with the choice of working extra hours to receive a larger paycheck, possibly on a day in which a particularly laborious task is being undertaken. Presumably, the duration of extra time, as well as the level of effort involved in the task, will factor into one’s decision to either accept the normal day’s pay or choose the larger paycheck. Yet, little research has been conducted in the laboratory to better understand how combinations of different costs might influence self-control decisions.

There is, however, substantial literature on the independent influences of delay and effort on self-control. Delay length has been studied extensively because of its inclusion in the standard laboratory definition of self-control (selection of a delayed large reward instead of an

Send correspondence to: Theodore A. Evans, Language Research Center, Georgia State University, 3401 Panthersville Road, Decatur, GA 30034, Phone: 404-244-5845, Fax: 404-244-5752, Email: theodore.evans@gmail.com.

All applicable institutional rules and regulations regarding animal care and use have been followed in the care and testing of the macaques. The experiments complied with all laws of the United States of America.

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immediate small reward). When manipulated independently in real-time, longer delay length (required for the large reward) or larger discrepancy in delay length (between that required for the small and large rewards), generally results in increased choice of the smaller more immediate reward in humans and non-human animals (hereafter referred to as animals) (e.g., see Beran, 1999; Beran & Evans; in press; Evans & Beran, in press; Grosch & Neuringer, 1981; Logue Forzano, & Tobin, 1992; Mischel, 1974; Rodriquez & Logue, 1986). According to Mischel (1981), this effect occurs because longer delay produces (at least in humans) a greater anticipation for the reward that, in turn, produces a level of frustration that reduces one's self-control.

Researchers have also shown that self-control is predictably influenced by the amount of effort associated with a response, in similar fashion to how delay interval influences self-control. For example, pigeons (*Columbia livia*) were tested in separate tasks in which they chose between: 1. pecking a key a small number of times to receive a small reward versus pecking another key a larger number of times to receive a large reward; and 2. pecking a key once and waiting a short duration for a small reward versus pecking another key once and waiting a long duration for a larger reward (Grossbard & Mazur, 1986). Pigeons' choices varied similarly with required effort and required delay, both producing "indifference curves" hyperbolic in shape.

In another study, similar in concept to the pigeon study above, adult human participants were asked to choose between two monetary options in a hypothetical scenario that involved different levels of delay or effort associated with obtaining each sum of money (Sugiwaka & Okouchi, 2004). As in the pigeon study, the investigators found that the same hyperbolic discounting function could be used to explain the negative influence of either delay or effort on self-control. Thus, from these studies we can conclude that delay and effort affect self-control in a similar fashion, when tested independently.

The above findings demonstrate interesting predictable effects when either delay length or effort level is manipulated independently in a self-control task. However, self-control decisions in the natural environment do not always incur just a single cost; instead, they may involve some combination of different costs (Eisernberger, Mitchell & Masterson, 1985; Eisenburger & Adornetto, 1986). Yet, we know little about how multiple costs, such as delay and effort, combine to influence self-control. The few investigations that have addressed this issue have provided mixed results.

In one study, human children received either delay training or effort training (i.e., they were reinforced for either tolerating long delays or working on high-effort conceptual tasks), and then were subsequently tested for self-control in the face of delay and effort (Eisenberger & Adornetto, 1986). Participants that received delay training exhibited greater self-control for delay, but not for effort, and participants that received effort training showed greater self-control for effort, but not for delay. This study demonstrated that delay and effort training effects do not generalize across delay and effort requirements, but the study did not specifically address the question of whether delay and effort levels influence choice behavior independently or interactively in real-time during self-control testing.

In another self-control study in which both delay and effort were tested, rat subjects were given the choice between pressing one lever to receive an immediate lesser reward and pressing a different lever to receive a delayed greater reward (Chelonis, Logue, Sheehy, & Mao, 1998). As experimenters steadily increased the amount of force (i.e., physical effort) required to press each lever, the rats chose the delayed reward more often (however, most rats stopped responding altogether when the required force exceeded a certain level). Chelonis and colleagues suggested that this response pattern resulted from subjects' attempts to offset increased energy expenditure (associated with increased response effort) by maximizing energy (i.e., food reward) intake. The results of this study demonstrated the effect of increased response effort required for both impulsive and self-control responses on delay discounting. However, it did not provide an assessment of how effort level and delay interval, varied between response choices, could influence self-control.

One study has been conducted in which both delay and effort requirements (among other variables) were varied simultaneously between response options while assessing choice behavior in real-time (Neef et al., 2005). In this study, normal children and children with attention deficit hyperactivity disorder (ADHD) were presented with choices between different arithmetic problems that were associated with variable reinforcement delay and response effort (as well as reinforcement rate and reinforcer quality). In baseline assessments that tested each variable independently, normal children and children with ADHD spent more time working on arithmetic problems that resulted in more immediate rewards or required less effort. In test sessions in which reinforcement delay and response effort conflicted directly (and other variables were held constant), the responding of children with ADHD was more influenced by reinforcement delay than response effort, but the responding of normal children was influenced equally by the two variables. However, because the duration of test trials was not always fixed, the number of trials completed within a test session depended partially on how quickly the individual could complete arithmetic problems. Therefore, this was not a true self-control paradigm because individuals could maximize reward earnings by selecting problems that could be completed most quickly, as opposed to selecting problems that provided the greatest payout.

To provide new insight into this issue, I tested rhesus monkeys in a computerized self-control task that allowed for different combinations of delay length and cognitive effort level associated with responding. Within trials of a fixed duration, subjects could select one or more stimuli in a learned sequence before selecting a “cash-out” stimulus that resulted in payment for each stimulus that was chosen in the correct order. Therefore, the monkeys could end a trial at any time and receive food pellets equal to the number of correct responses they made on that trial. The longer the animals worked on a trial, the more food they could receive, but the sooner they cashed-out the sooner the food was actually presented. This created a self-control situation in which delaying reinforcement for responding led to a greater potential amount of reinforcement. Because all trials were of equal duration, the only way to maximize the number of reinforcements was to delay reward presentation in this manner.

I tested macaques with this method in two separate experiments. First, I established the validity of the task as a self-control assessment by testing for an effect of delay, alone, on monkeys’ willingness to select multiple computerized images in sequence prior to receiving rewards. Delay was varied by manipulating the speed of the cursor used to sequence images.[1] I hypothesized that monkeys would select fewer stimuli prior to cashing-out when delay length was longer (i.e., when cursor speed was slower), even though this would lead to fewer rewards during a session.

In the second experiment, I tested monkeys in the same task, but with different levels of both delay and cognitive effort (hereafter referred to as effort). Delay and effort were varied systematically across test sessions by manipulating the speed of the cursor used to sequence images and the memory demand for the sequential order of the stimuli, respectively. The memory demand was manipulated by presenting stimuli in one of two fashions. In the less demanding condition, stimuli were always presented in the same configuration on the screen with the first, second, third, and fourth stimuli presented in the full-left, left-center, right-center,

[1]Although the delay variable did involve an inherent physical cost (i.e. maintaining control of the cursor for relatively shorter and longer durations of time), this cost was minor due to the large amount of experience the monkeys had using the joystick.

and full-right positions, respectively. In the more demanding condition, a different set of images was used, and stimuli were moved to new positions across trials, so that the monkeys could not simply repeat a motor sequence as they could in the less demanding condition. In this condition, the monkeys had to remember which stimulus was the next correct item to be selected, and they had to employ a search strategy to locate the item, thereby exerting a greater level of cognitive effort.

This method provided a real-time assessment of the combined influence of these variables on self-control. I hypothesized that delay length and effort level would act together to influence self-control negatively because each typically has a negative effect on self-control when tested independently. More specifically, I expected the negative influence of the two variables to be additive, meaning that the most self-control would be exhibited when delay was short and effort was low, and that the least self-control would be exhibited when delay was long and effort was high. Finally, I hypothesized that delay length would influence self-control more than the level of cognitive effort would, because the monkeys had more experience with different task varieties (some more difficult than others) than they had with variable cursor speed (though, a difference in effect size between these variables may not necessarily be attributable to differential experience with each variable). This difference in effect size would be evident if more self-control was shown when delay was short than when delay was long, both when effort was low and when effort was high.

Experiment 1

Method

Subjects—Four male rhesus macaques were tested including Gale (age 23), Chewie (age 7), Luke (age 7), and Obi (age 3). Monkeys were individually housed with constant visual and auditory access to other monkeys. Monkeys had 24-hour access to water and computerized testing systems (Richardson Washburn, Hopkins, Savage-Rumbaugh, & Rumbaugh, 1990), from which they could earn banana flavored grain-based food pellets. They were fed manufactured chow and various fruits and vegetables daily between 1600 and 1800 hours. One monkey (Gale) was previously employed in a computerized, delay-choice, self-control task (Beran, unpublished data), and all four monkeys were previously tested in a non-computerized delay maintenance self-control task (Evans & Beran, in press). All four monkeys also had a large amount of experience with computerized testing in several different cognitive and psychomotor tasks.

Apparatus—The monkeys were tested using the Language Research Center's Computerized Test System (LRC-CTS; Richardson et al., 1990). This system allowed monkeys to manipulate a joystick outside of their home cage by reaching through the cage mesh. The joystick controlled a cursor on a computer monitor, and the computer automatically delivered 94-mg fruit flavored pellets (Bio-Serv, Frenchtown, NJ) for correct responses through a dispenser interfaced to the computer using a relay box and output board (Keithley Instruments, Cleveland, OH).

Procedure—Monkeys were trained to use the LRC-CTS to complete a stimulus-sequencing task. At the beginning of each trial, two to four stimuli of unique appearance were positioned randomly along the border of the top half of the screen in front of a solid white background (Figure 1). A small circular cursor was positioned in the center of the screen, equidistant from all stimuli, and could be controlled by the monkey by moving a joystick. Using the most efficient cursor path (i.e., a straight line), the cursor could be moved from its origin to any stimulus in 6 s or less, depending on the experimental condition. Once the cursor contacted a stimulus, both the cursor and stimulus would disappear. If the correct stimulus was selected, a brief high-pitch tone sounded, and the cursor reappeared in the center of the screen, allowing the subject to select additional stimuli (except after the selection of the final stimulus, at which point all images including the cursor would disappear, leaving only the white background on the screen). Selecting a correct stimulus earned the subject one pellet, to be dispensed at the completion of the stimulus set. If an incorrect stimulus was selected at any point during the trial, a low-pitch buzzer sounded, and all stimuli disappeared. Each trial lasted 60 s, timed from the selection of the first stimulus. In all trials, the stimulus set could be sequenced in less than 30 s, but if a monkey paused for several seconds between stimuli, it would be possible for a trial to not be completed within 60 s. At the end of 60 s, any ongoing activity ceased including cursor movement, stimulus visibility, and reward delivery, and the next trial's stimulus set was automatically presented. Trials were presented in 4-hour blocks, three to four times per week, between the hours of 0900 and 1700.

Training: Monkeys were trained to select two to four stimuli in the predetermined order to receive a food reward (see Fig 1b for the Experiment 1 stimulus set). Monkeys were first presented with training trials involving two stimuli until they reached an 80% success criterion (within the most recent 100 trials). A third stimulus, and later, a fourth stimulus were each added as monkeys continued to meet the 80% success criteria. Monkeys earned one food pellet for each stimulus selected in appropriate order, all of which were dispensed after all available stimuli had been properly sequenced. However, if any stimulus was selected out of sequence, a buzzer sounded, all stimuli disappeared, and no food rewards were dispensed. Finally, the monkeys were trained to move the cursor to a bar shaped cash-out stimulus that appeared at the bottom of the computer screen after all other stimuli had been correctly sequenced, in order to receive their earned food reward (Fig. 1a). No additional pellets were earned for selecting the cash-out stimulus. Training sessions with the cash-out stimulus included an equal number of two-image, three-image, and four-image trials, so that no particular response category would be over-reinforced. During all training sessions, the speed of the cursor (and therefore, the delay length) was set at a moderate level in comparison to cursor speed in subsequent test sessions (see below). Individuals required between 1,000 and 4,500 total training trials to reach the 80% correct criterion on trials involving two, three, and four stimuli, as well as the cash-out bar.

Testing: The stimulus set used in training was presented to subjects again during test sessions. At the beginning of each test session, a block of 20 "forced" trials was presented, in which the subject was required to select all visible stimuli in appropriate order before the cash-out stimulus would appear. An equal number of one-image, two-image, three-image, and four-image forced trials were presented in random order within the 20-trial block. Any forced trials in which stimuli were selected out of order were repeated at the end of the block. Following completion of the forced-trial block, test trials were presented for the remainder of the 4-hour test session. In test trials, all four stimuli always appeared at the beginning of the trial, and the cash-out stimulus was made available to subjects after each appropriate sequencing response.

Testing was conducted across four sessions, in which the amount of time required to select stimuli (i.e., delay length) was varied. The amount of time required to select stimuli was manipulated by altering cursor speed. In the first and second sessions, more time was required to select stimuli in sequence because the cursor moved slowly between its central position and the four test stimuli. At the most efficient rate of responding, each selection required approximately 6 s in these trials. In the third and fourth sessions, less time was required to sequence stimuli, because the cursor moved quickly between its central position and the four test stimuli (each selection required approximately 2 s). In both conditions, the cursor was set to move quickly between the center screen and the cash-out stimulus (approximately 2 s). Thus, full completion of a short delay trial would require a minimum of 10 s (2 s to select each of the four test stimuli + 2 s to select the cash-out stimulus), and full completion of a long delay trial would require a minimum of 26 s (6 s per test stimulus + 2 s to cash-out). During training

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trials, the cursor was set to move at a moderate speed (approximately 4 s per response) so that responding during short delay and long delay test sessions was not influenced by reinforcement history with those cursor speeds.

Analysis—In previous self-control research with these animals, large individual differences were found in willingness to delay gratification (Evans & Beran, in press). I expected a similar degree of individual variation in the present experiment and performed separate analyses on each individual's data, whenever possible. Thus, each monkey's test data were analyzed separately for an influence of delay length on self-control. In order to obtain sufficient statistical power in these analyses, each monkey's data set was divided into 4-trial blocks, and the mean number of images selected before cashing-out was calculated for each block. Block means were then analyzed with independent-samples *t* tests (one-tail; $\alpha = 0.05$) to assess whether an individual monkey's score was higher in the short delay condition than in the long delay condition.

Results and Discussion

All descriptive and inferential statistics conducted on Experiment 1 test data are presented in Table 1. Monkeys completed between 68 and 286 test trials per condition, of which 61% to 87% were completed without sequencing error. In 100% of error-free test trials in the short delay condition, monkeys selected at least two stimuli before moving the cursor to the cash-out stimulus to receive their earned rewards. Further, monkeys selected all four stimuli before cashing-out in 61% to 100% of short delay trials. Thus, in trials of fixed duration, monkeys forwent the opportunity to receive a small food reward for cashing-out after selecting just one stimulus (and often two or three stimuli), in order to work longer in the task and earn a food reward of greater size. This description of the monkeys' performance is consistent with the standard laboratory definition of self-control (the choice of a delayed larger reward over an immediate small reward). Moreover, even though the total duration for which monkeys were required to delay gratification in short delay trials (10 s) was modest, it was very similar to time delays employed in more typical self-control tasks conducted with this and related species (see Tobin, Logue, Chelonis, & Ackerman, 1996;Szalda-Petree, Craft, Martin, & Deditius-Island, 2004).

In error-free trials of the long delay condition, however, monkeys did not always select multiple stimuli before cashing-out. Luke showed a strong bias for the one-image response category in the long delay condition (89% of trials), and Chewie, Gale, and Obi selected one image before cashing-out in a small proportion (2% to 13%) of long delay trials. Thus, in the long delay condition, fewer individuals forwent the opportunity to receive a lesser food reward for cashing-out after selecting just one stimulus, than in the short delay condition. Additionally, each individual selected fewer images before cashing-out in long delay trials than in short delay trials, and this difference was statistically significant for three of the four monkeys.

These results indicate that the monkeys' self-control was influenced by the length of delay associated with the response. Specifically, when delay length was longer, monkeys were less willing to sequence multiple stimuli in order to maximize reward value. This pattern of responding is consistent with the results of other self-control/decision making tasks in which animals had to discount delay to maximize reward amount (see Logue, 1988, for a review), including a previous study in which all of these subjects participated (Evans & Beran, in press).

There was, however, one uncontrolled variable that could have confounded the results of Experiment 1. Delay length co-varied with session presentation order; short delay sessions were presented first, and long delay sessions were presented last. However, it was unlikely that this presentation order had such an effect, because as time progressed, fewer images were selected before cashing-out. A more likely presentation order effect would have been a practice effect, in which subjects' performance improved over time. Nonetheless, presentation order was randomized in the subsequent experiment to control for the possibility of such an effect.

Experiment 2

Method

Subjects, Apparatus, & General Procedure—The same four subjects from Experiment 1 were tested with the LRC-CTS using the same general procedure.

Training

In Experiment 2, two different sets of stimuli were trained, each representing a different level of the effort variable (Figure 1b). The low effort set was trained first, in a similar manner to the procedure used in Experiment 1, with one exception. Because subjects had already proven proficient with the cash-out stimulus, it was included in all Experiment 2 training trials. The low effort set consisted of four images that always appeared in the same configuration on the monitor (in left to right order). The high effort set was trained second, in the same manner. This set consisted of four completely different images that appeared in a new random configuration in each trial. Thus, in the high effort condition, the monkeys had to employ a search strategy to locate the item, in addition to remembering which stimulus was the next correct item to be selected, thereby exerting a greater level of cognitive effort.

Testing

Each monkey was presented with 12 test sessions with varied delay lengths and effort levels. As in Experiment 1, delay was manipulated by adjusting cursor speed. Effort level was varied by presenting stimuli in either fixed or random configuration (see above). Three sessions were presented with each delay length/effort level combination, and session presentation order was randomized within subjects. At the beginning of each test session, monkeys were required to correctly complete fifteen forced trials similar to those used in Experiment 1. Forced trials were followed by 60 test trials, in which the cash-out stimulus was made available after each accurate response.

Analysis

As in Experiment 1, analyses were conducted at the individual level whenever possible, in expectation of sizeable individual differences in performance. Two analyses were conducted to verify the assumption that the two levels of the effort variable actually required different levels of cognitive effort from the monkeys. First, training data were analyzed to assess whether the monkeys required more training trials to reach the 80% success criterion with the high effort stimulus set than with the low effort stimulus set. A related-samples *t* test (one tail; $\alpha = 0.05$) was used for this analysis, including all four subjects' training data, because adequate statistical power could not be obtained through individual analyses. Second, the number of sequencing errors committed during Experiment 2 forced trials were compared across experimental condition to test whether effort level (or delay length) influenced sequencing accuracy. To achieve greater statistical power, an individual monkey's sequencing errors were grouped by session and tested with a two-way analysis of variance ($\alpha = 0.05$). Forced trials, and not test trials, were used for this analysis because animals could not cash out early (i.e., before sequencing all stimuli) during forced trials. Cashing-out early reduces the likelihood of committing an error, and therefore would confound an analysis of error rates based on task difficulty. Previous research has shown that rhesus monkeys can monitor their own states of uncertainty and use such knowledge to 'escape' from more difficult trials, thereby avoiding committing errors in computerized tasks (see Smith Beran, Redford, & Washburn, 2006).

Finally, error-free test trial data were analyzed individually using two-way analyses of variance ($\alpha = 0.05$) to assess how delay and effort influenced each monkey's self-control. In order to obtain sufficient statistical power in these analyses, each monkey's data set was divided into 5-trial blocks, and the mean number of images selected before cashing-out was calculated for each block. Block-means from each condition were then analyzed as independent data points in the analysis of variance. Eta Squared (η^2) values were calculated to represent the magnitude of effect (more specifically, the percentage of total variance) associated with each independent variable and the interaction between these variables. Simple main effects were analyzed post hoc to evaluate any apparent response patterns within subsets of the full dataset.

Results and Discussion

All inferential statistics conducted on Experiment 2 training data and forced trial data are presented in Table 2. During training, monkeys required significantly more trials to reach the final 80% success criterion with the high effort stimulus set than with the low effort stimulus set. This suggested that the high effort set was more demanding than the low effort set. This effect was supported by monkeys' performance during forced trial blocks that were presented throughout the test phase (Figure 2). Three of the four monkeys exhibited a main effect of effort level on the amount of errors committed during forced trials, with significantly more sequencing errors occurring during high effort trials than during low effort trials. Chewie, however, did not commit more errors in forced trials as a function of effort level but did err differentially as a function of delay interval. Interestingly, Chewie demonstrated decreased accuracy during short delay trials, suggesting that he may have benefited from the extra processing time provided by the slower cursor in long delay trials.

All descriptive and inferential statistics conducted on images selected in Experiment 2 are presented in Table 3. For three monkeys, a significant interaction effect between delay and effort was found with respect to the number of images selected before cashing-out. The interaction effect accounted for 3% to 11% of the total variance of these monkeys' responses. The fourth monkey (Gale) showed separate main effects of delay and effort on the number of images selected before cashing-out, each of which accounted for 4% of the total variance in responses. Thus, most monkeys' self-control was influenced, to some extent, interactively by delay length and cognitive effort level.

Subjects whose self-control was influenced by delay and effort, interactively, exhibited certain commonalities between their response patterns. Most strikingly, all three individuals selected more images before cashing-out in short delay trials than in long delay trials, both when effort was low and when effort was high (Figure 3). This response pattern produced a significant main effect of delay length on self-control for all three of these individuals. This effect accounted for 12% to 90% of the overall variance of these animals' responses.

Additionally, these three monkeys showed a common response pattern with regard to effort level within the subset of short delay trials. All three monkeys selected a greater number of images prior to cashing-out in low effort/short delay trials in comparison to high effort/short delay trials (Figure 3). This response pattern produced a significant simple main effect of effort level within short delay trials for Luke and Obi (but not Chewie).

In the final subset of trials (long delay trials), however, these three monkeys' response distributions were much more variable (Figure 3). Chewie selected more images before cashing-out in high effort/long delay trials than in low effort/long delay trials, and Obi showed the opposite effect. These two individuals showed significant (but opposite) simple main effects for effort level within this subset of trials. Further, Obi showed a significant main effect of effort level for the full data set, which accounted for 61% of his total variance. Unlike Chewie and Obi, Luke selected an equal amount of stimuli before cashing-out in both conditions and showed no statistically significant effect within this subset of trials. Thus, when delay length was long, each of these individuals' self-control was influenced differently by effort level.

General Discussion

This computerized image-sequencing task provided a reliable measure of monkey self-control, in that most individuals were willing to work longer in trials of fixed duration in order to maximize earned food rewards. In Experiment 1, all monkeys delayed gratification for the entire stimulus set in nearly all short delay trials (~10 s), and three of the four monkeys delayed gratification for the entire stimulus set in a majority of long delay trials (~26 s). However, their self-control was reduced significantly by the longer delay interval. In the second, more comprehensive experiment, monkeys' responding continued to be influenced by delay length in a similar manner in all subsets of trials. This relationship between delay length and self-control is consistent with the results of many previously conducted self-control studies (see Logue, 1988, for a review). Further, the durations employed in this task fall within the range of delay intervals that these and other rhesus monkeys have been willing to endure in previous investigations of self-control (Anderson & Woolverton, 2003; Evans & Beran, in press).

Performance in Experiment 2 also suggested a complex interaction between delay length and effort level on monkeys' self-control. Three monkeys showed a significant interaction effect, while only one monkey exhibited independent (though, apparently weak) main effects of these variables on self-control. Prior to conducting the study, I predicted the combined influence of these two variables to be additive and negative, meaning that the most self-control would occur in short delay/low effort trials and the least self-control would occur in long delay/high effort trials. Such a pattern of responding would have most likely produced two separate main effects in the analysis of self-control scores. Because the predicted response pattern and statistical result were evident for only one monkey (Gale), this hypothesis was not supported.

One major element seemed to have prevented the majority of monkeys' response patterns from showing the originally predicted additive influence. These monkeys showed a consistent negative relationship between delay length and self-control but showed an inconsistent relationship between effort level and self-control. Monkeys' self-control appeared to be influenced negatively by effort level when delay length was short, but each animal showed a different response to effort level when delay length was long. For this reason, each of these monkeys' response patterns could not be simply described by an additive effect of delay length and effort level on self-control.

Prior to conducting the study, I also hypothesized that delay length would influence subjects' self-control more than effort level (presumably because of differential experience the monkeys had with each variable). Such a difference in effect size between variables would have resulted in significantly more self-control in short delay trials than in long delay trials, both when effort was low and when effort was high. If this pattern was seen, one would also expect the delay variable to account for a larger portion of variance in the dataset than the effort variable. Chewie and Luke's data sets displayed both of these characteristics, supporting the hypothesis. However, Obi's performance indicated a stronger influence of effort level than of delay length, and Gale's self-control was influenced equally by each variable. Thus, these two variables influenced each individual's self-control to a different degree. Because of these individual differences, this data set did not provide a clear answer to the question of which variable was more influential on monkeys' self-control.

The answers to several of the questions posed in this study are related to individual differences in performance. In Experiment 2, most monkeys exhibited an interaction effect on their self-control scores, but the response pattern underlying the interaction was unique to each monkey.

Contributing to these underlying response patterns, were the very different reactions that individual monkeys exhibited in response to required effort level. Further, while most monkey self-control was consistently influenced by the delay variable, the (relative) magnitude of that influence was unique to each monkey. If one were to consider only the group mean performance from this experiment (see Figure 3), he or she would conclude that the self-control of the rhesus monkey is influenced negatively and to a moderate degree by each of these independent variables. However, because of the abovementioned individual differences associated with each primary effect, this summary would not accurately portray the performance of of the tested individuals.

Substantial individual differences in self-control are not unique to the results of this study. In a previous investigation, participants of the present study and several conspecifics showed remarkable variability in their willingness to delay gratification for consecutively presented food items in a simple task (Evans & Beran, in press). Other nonhuman primate species have also shown notable individual differences when tested for self-control in related tasks (e.g. Anderson et al., 2000; Beran & Evans, 2006; Beran et al., 1999); however, little is known about the factors that contribute to such between-subjects variability. Future investigations of self-control and impulsivity should continue to attempt to explain these individual differences, as they may provide insight into self-control deficits in humans. In addition, further research with a focus on the relationship between multiple variables and self-control will likely improve our understanding of choice behavior in both humans and animals.

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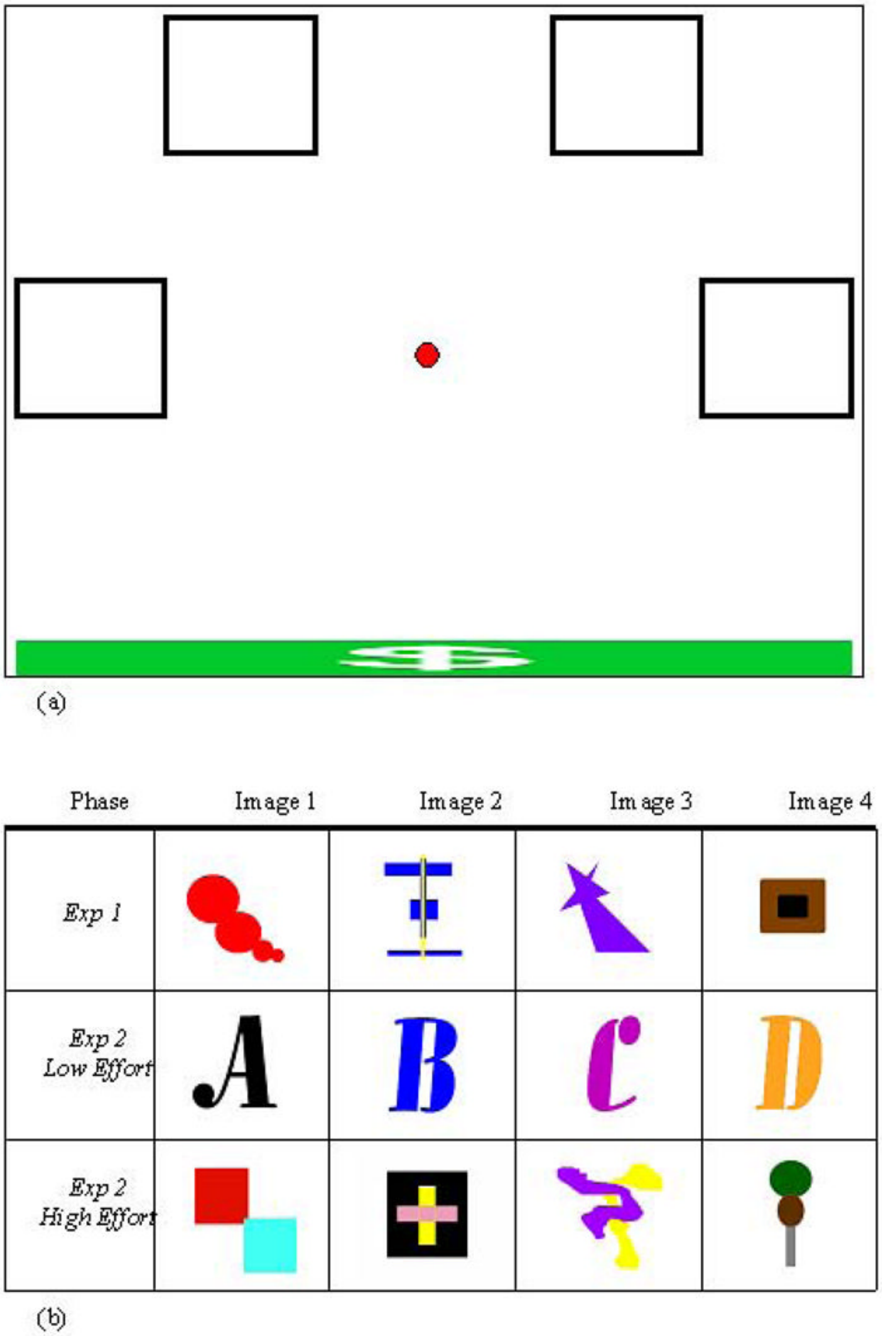

Figure 1.

General Procedure (a): Stimuli to be sequenced were presented along the border of the top half of the test screen, the cursor was presented at the center of the screen, and the cash-out stimulus was presented at the bottom of the screen (the cash-out stimulus appeared only after at least one correct sequence-response and never at the beginning of the trial).

Stimulus Sets (b): Different stimuli were presented in Experiment 1 and in each level of the effort variable in Experiment 2.

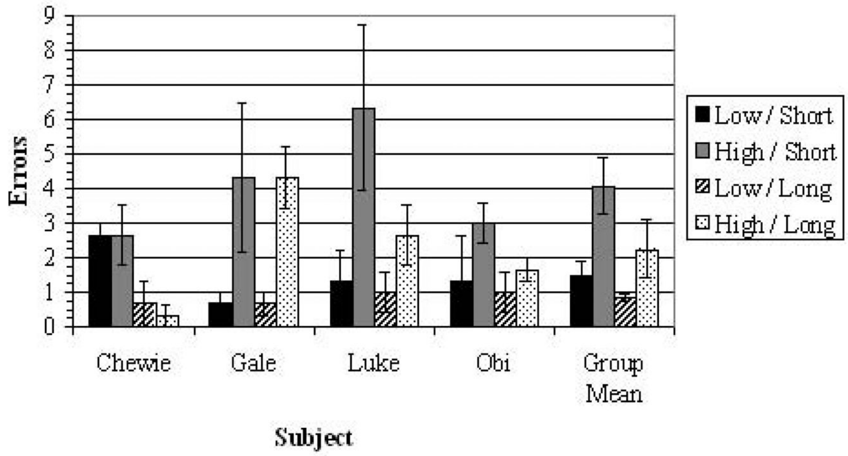

Figure 2.
Sequencing errors committed during forced-trial blocks at the beginning of the Experiment 2 test sessions. Bar height represents mean number of errors per block bar color represents experimental condition, and error bars represent the standard error of the mean. Bars are clustered by individual, and a final cluster is provided to represent the mean performance of the entire group.

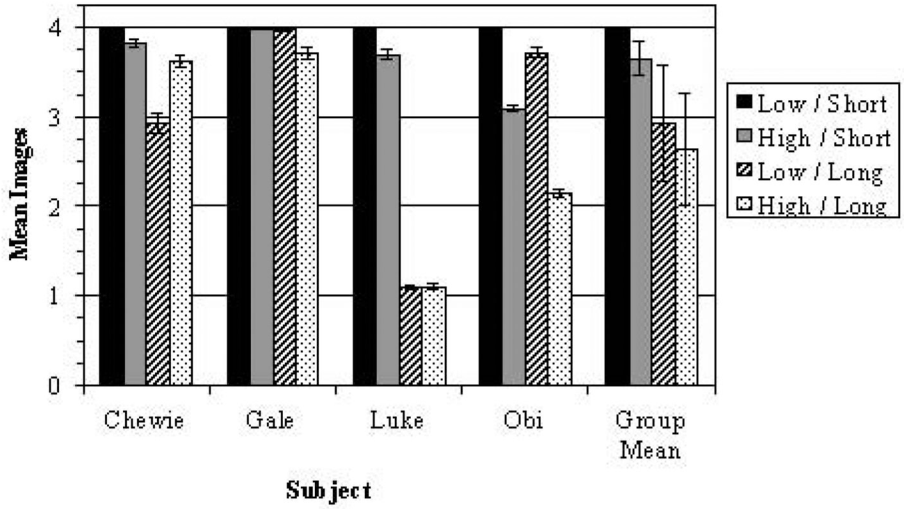

Figure 3.

Mean number of images selected before "cashing-out" in each condition of Experiment 2. Bar height represents mean image selection, bar color represents experimental condition, and error bars represent the standard error of the mean. Bars are clustered by individual, and a final cluster is provided to represent the mean performance of the entire group.

Table 1

The number of images selected before cashing-out by each animal in each condition of Experiment 1, and the results of individual analyses conducted on those data.

Condition	Statistic	Subject			
		Chewie	Gale	Luke	Obi
Short delay	N Trials	68	177	136	193
	% Correct	81	82	61	85
	% 1	0	0	0	0
	% 2	0	1	3	0
	% 3	0	1	21	2
	% 4	81	80	37	83
	Mean	4.00	3.97	3.56	3.99
Long delay	N Trials	137	286	141	69
	% Correct	82	81	87	84
	% 1	4	10	77	2
	% 2	3	2	3	4
	% 3	2	14	2	2
	% 4	73	55	5	76
	Mean	3.77	2.95	1.31	3.83
Result	t_{Delay}	1.194	5.214*	10.429*	1.791*
	df	40	69	51	54

*Significant at $p < 0.05$.

Table 2

The number of Experiment 2 training trials that each monkey required to reach an 80% success criterion with the low effort and high effort stimulus sets, and the results of analyses conducted on those data and Experiment 2 forced-trial data.

(Training trials to criterion)		**Subject**			
Condition	**Statistic**	**Chewie**	**Gale**	**Luke**	**Obi**
Low effort	N	330	310	430	200
High effort	N	551	444	660	423
Result	t_{Effort} df	8.880* 3			
(Forced trial errors – see Figure 2 for the raw data)					
Results	$F_{Delay,Effort}$ df, N	0.077 1, 12	0.000 1, 12	1.449 1, 12	3.063 1, 12
	F_{Delay} df, N	13.000* 1, 12	0.000 1, 12	2.087 1, 12	3.063 1, 12
	F_{Effort} df, N	0.077 1, 12	9.308* 1, 12	5.797* 1, 12	7.563* 1, 12

* Significant at $p < 0.05$.

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Table 3

The number of images selected before cashing-out by each animal in each condition of Experiment 2, and the results of individual analyses conducted on those data.

Condition	Statistic	Subject			
		Chewie	**Gale**	**Luke**	**Obi**
Short delay, Low effort	N	179	180	180	180
	N Correct	174	169	173	155
	% 1	0	0	1	0
	% 2	0	0	0	0
	% 3	1	0	0	3
	% 4	99	100	99	97
Short delay, High effort	N	175	179	176	180
	N Correct	131	175	107	158
	% 1	2	0	3	3
	% 2	2	1	2	1
	% 3	8	0	19	17
	% 4	88	99	77	79
Long delay, Low effort	N	178	173	199	179
	N Correct	166	114	191	166
	% 1	35	0	94	1
	% 2	0	0	4	8
	% 3	2	3	1	74
	% 4	63	97	2	18
Long delay, High effort	N	179	176	180	180
	N Correct	132	130	166	169
	% 1	6	2	92	5
	% 2	4	5	7	*78*
	% 3	14	14	2	16
	% 4	76	79	0	2
Results (simple main effects)	$F_{Delay\ X\ Effort}$	7.091*	2.900	4.526*	15.994*
	df, N	1, 122	1,99	1, 130	1, 131
	η^2	0.057	0.030	0.033	0.112
	F_{Delay}	16.148*	4.298*	1102.532*	47.564*
	df, N	1, 122	1,99	1, 130	1, 131
	η^2	0.12	0.043	0.897	0.272
	F_{Effort}	2.686	4.333*	3.213	198.920*
	df, N	1, 122	1,99	1, 130	1, 131
	η^2	0.022	0.044	0.025	0.610
	$F_{Delay\ (low)}$	25.221*	0.083	758.059*	4.163*
	df, N	1, 68	1, 57	1, 75	1, 65
	$F_{Delay\ (high)}$	0.824	6.070*	411.059*	59.853*
	df, N	1, 54	1, 42	1, 55	1, 66
	$F_{Effort\ (short)}$	0.520	0.066	6.370*	49.169*
	df, N	1, 61	1, 49	1, 56	1, 63

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Condition	Statistic	Subject			
		Chewie	**Gale**	**Luke**	**Obi**
	$F_{Effort\ (long)}$	9.325*	7.852*	0.044	170.387*
	df, N	1, 61	1, 50	1, 74	1. 68

*Significant at $p < 0.05$.