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Moving Evidence into Practice: Cost Analysis and Assessment of Macaques' Sustained Behavioral Engagement with Videogames and Foraging Devices

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Abstract

Environmental enrichment plans for captive nonhuman primates often include provision of foraging devices. The rationale for using foraging devices is to promote species-typical activity patterns that encourage physical engagement and provide multi-sensory stimulation. However, these devices have been shown to be ineffective at sustaining manipulation over long periods of time, and often produce minimal cognitive engagement. Here we use an evidence-based approach to directly compare the amount of object-directed behavior with a foraging device and a computer-based videogame system. We recorded 11adult male rhesus monkeys' interactions with a foraging device and two tasks within a joystick videogame cognitive test battery. Both techniques successfully produced high levels of engagement during the initial 20-min of observation. After 1-hr the monkeys manipulated the foraging device significantly less than the joystick, $F(2,10)= 43.93$, $p < .0001$. Subsequent testing showed that the monkeys engaged in videogame play for the majority of a 5-hr period, provided that they received a 94mg chow pellet upon successful completion of trials. Using a model approach we developed previously as a basis for standardized cost:benefit analysis to inform facility decisions, we calculated the comprehensive cost of incorporating a videogame system as an enrichment strategy. The videogame system has a higher initial cost compared to widely-used foraging devices however, the ongoing labor and supply costs are relatively low. Our findings add to two decades of empirical studies by a number of laboratories that have demonstrated the successful use of videogame-based systems to promote sustained non-social cognitive engagement for macaques. The broader significance of the work lies in the application of a systematic approach to compare and contrast enrichment strategies and encourage evidence-based decision making when choosing an enrichment strategy in a manner that promotes meaningful cognitive enrichment to the animals.

Keywords

primate; animal welfare; refinement; occupational enrichment; video-joystick

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Introduction

The psychological well-being of captive nonhuman primates (NHPs) is important to the research community, both as a matter of moral concern for animal welfare and as an integral factor that can affect the results, interpretation, replicability, and generalizability of scientific studies. Research on the effects of environments on animals' brain, behavior, and health, occurred for decades prior to formal regulation and establishment of voluntary accreditation organizations that certify the care of captive animals in laboratory or in zoological settings [Krech, Rosenzweig, & Bennett, 1960; Benefiel, Dong, & Greenough, 2005; for additional references and review, see Renner & Rosenzweig, 1987]. In 1985, however, specific provision for environmental enrichment was formalized into federal law in the United States. The Animal Welfare Act (AWA) is the central federal legislation in the US that governs the care of nonhuman primates (NHP) in research facilities and public settings such as zoos, entertainment venues, and breeders or dealers. An amendment to the AWA in 1985 formalized the legal requirement for facilities overseen by the United States Department of Agriculture to have a written Environmental Enrichment Plan (EEP) that addresses the psychological welfare of NHP [Animal Welfare Act, 1985; Title 9 C.F.R., Chapter 1, Subchapter A - Animal Welfare, Parts 3, Section 3.81]. The requirement applies to facilities registered by the USDA to perform research with nonhuman primates, as well as to those facilities licensed by the USDA for the use of nonhuman primates in entertainment, breeding, or other purposes.

The AWA amendment and EEP requirement spurred an increase in publication of systematic research aimed at refining NHP care and enrichment techniques. For the most part, those studies have focused on what types of enrichment the animals interacted with, or used frequently, and whether the provision of different forms of enrichment changed the animals' behavior or measures associated with stress, health, and well-being. On the behavioral side outcome measures ranged from reduction of abnormal behaviors (e.g., stereotypies, self-injurious behavior) to increases in activity in general, or to species-typical behavior in particular (e.g., foraging, play). On the physiological side outcome measures included stress hormones, alopecia, and somatic health. Very few of these studies included evaluation of relative cost, longer-term outcomes, or direct and rigorous comparisons of enrichment strategies in common use. In parallel to the increase in studies of NHP enrichment was an increase in scientific and trade organization conference sessions on enrichment, as well as training and education programs designed to promote environmental enrichment.

Despite the increase in empirical literature, conference sessions, and training workshops, there remains an absence of clear consensus on what constitutes best practices for many aspects of environmental enrichment for NHP. As a result, adoption of various enrichment strategies remains idiosyncratic across facilities and largely unaddressed by formal policy. Thus, 30 years after the 1985 AWA amendment unevenness in application of evidence-based practices for primate enrichment occur across the wide range of facilities that house primates in captivity in the US [Baker, Weed, Crockett, & Bloomsmith, 2007; Baker, 2016]. It is this gap between evidence and practice—or even policy—that is the focus of a line of research that aims to encourage adoption of standardized approaches to the assessment of environmental enrichment for NHP [Bennett et al., 2010, 2014]. The approach has two core assumptions: First, that failure to achieve widespread adoption of enrichment strategies previously demonstrated to produce benefit in terms of behavioral, physiological, or health outcomes measures is attributable in part to failure to adequately address practical, financial, or policy considerations. Secondly, that providing rigorous assessment of practical and cost information for enrichment strategies previously demonstrated to have animal welfare benefit is critical to inform decision-making and implementation. Thus, the approach taken here and in our previous work, as illustrated in Figure 1, is to select candidate enrichment strategies that have already been demonstrated to produce substantial benefit to NHP and then conduct a comprehensive cost analysis. The analysis is targeted to address the specific interests of a range of stakeholders involved in decision-making at facilities housing NHP, as well as those seeking information relevant to policy decisions. The stakeholders include personnel charged with budgetary considerations and personnel charged with supervision of husbandry and enrichment personnel. In turn, the objective of the analysis is to directly address common potential obstacles that contribute to the gap between the empirical literature supporting best practices in NHP enrichment and the actual practices in common use.

Over the past several decades, a number of approaches have guided both empirical studies of environmental enrichment and selection of enrichment strategies. Some take a clinical, or treatment-targeted, approach that is aimed at reducing abnormal behavior. The clinical approach is critically important, but is insufficient to capture the needs of the majority of the captive NHP population. Thus, the approach emphasized in our model is to select enrichment strategies that promote species-typical manipulative interaction and cognitive engagement for all animals, not only the small minority that evidence abnormal behaviors. In turn, the method of comprehensive cost analysis [Bennett et al., 2010] addresses the goal of assessing relative *value* based on *both* cost and benefit, where benefit is operationalized in terms of use by the monkeys. The decision to use interaction with the enrichment as a marker of benefit reflects multiple considerations. First, for enrichment strategies for which there is already evidence of benefit (e.g., behavioral or physiological evidence of improved animal welfare) it is sufficient to demonstrate use by NHP, rather than additional evidence of impact on other measures of well-being. Second, given that the rationale for enrichment most often revolves around giving the monkeys "something to do," or something to promote active engagement and sensory stimulation, time on task or amount of manipulation, or interaction with enrichment devices is a reasonable measure of utility. Finally, that interaction with devices is a simple and feasible measure that can be effective in screening enrichment strategies and making cross-species and cross-facility comparisons. Perhaps most importantly, the approach does not focus solely on reduction of abnormal behavior. Thus, it is inclusive of the majority of monkeys who do not express abnormal behavior. Furthermore, the approach does not depend on having a sufficient population of animals with abnormal behavior in order to determine effective enrichment strategies for the remainder of the animals.

We have focused on enrichment strategies that dominate practices used in facilities that house NHP as well as those practices that are supported by the scientific literature on primate cognition, behavior, and health. The two criteria are often not overlapping. For example, from the range of enrichment strategies employed in research, zoo, sanctuary, and other captive settings are the use of: foraging devices, manipulanda, murals painted on housing walls, provision of scented potpourri or other olfactory stimuli, exposure to radio music, television or movie viewing opportunities, children's toys, stuffed animals and dolls, swings, and climbing structures. Empirical evidence for animals' engagement with these various enrichments is uneven and sometimes missing entirely. Moreover, for some enrichment efforts, there is little evidence to suggest that they have high interactive value, are effective in engendering species-typical behavior, or produce a benefit to the animals. By contrast, decades of psychological science provides strong support for the interactive value of puzzles, learning games, and other tasks that provide cognitive challenge, contingent feedback or reward, and stimulation across sensory domains (i.e., tactile, visual, auditory). Yet there remains little evidence that these forms of complex cognitively engaging enrichment are in widespread or routine use by enrichment programs [Baker et al., 2007; Baker, 2016].

In a previous study, we evaluated commonly used foraging devices for their ability to elicit sustained interaction from macaques, while also taking into account the costs associated with initial purchase, supplies, and labor (Bennett et al., 2014). Although costs were shown to be relatively low (averaging less than US$1 per foraging opportunity) and all elicited high engagement in the first hour, none of the devices successfully sustained high levels of foraging behavior one to two hours after delivery. This was likely due in part to the fact that these devices effectively provided the monkeys with a simple manual task, but posed little cognitive challenge and did not permit replenishment as the devices were emptied of forage food.

Psychologists have long known that many nonhuman animals, including primates, are intrinsically motivated to explore and manipulate objects in their environment [Klüver, 1933; Berlyne, 1950; Welker, 1961; Fowler, 1965]. For example, Harlow [1950] demonstrated that rhesus macaques (*Macaca mulatta*) learned to solve a complex six-step mechanical puzzle without any extrinsic incentive (e.g., food reward or treat), and continued to engage the device for long periods of time. Here we evaluate an enrichment strategy that was not available at Harlow's time; one which allows NHPs to make use of their sensory, perceptual, and motor skills to obtain both intrinsic and extrinsic incentives: the National Aeronautics and Space Administration NASA)/Language Research Center (LRC) Computerized Test System [CTS; Richardson, Washburn, Hopkins, Savage-Rumbaugh, & Rumbaugh, 1990; Washburn, 2015]. Developed at the Georgia State University Language Research Center, the LRC-CTS is an automated system which can be used to "provide environmental enrichment to nonhuman primate subjects in ways that would complement and even contribute to the bio-behavioral science that justified the monkeys' captivity" [Washburn, Rumbaugh, & Richardson 1992c, p. 11]. The LRC-CTS includes an auto-shaping procedure that is used to train subjects to control an on-screen cursor using a joystick. When this basic skill is mastered, and the learner becomes proficient at tracking and making the cursor contact a moving target, they can readily be introduced to a variety of tasks in the cognitive test battery.

There is robust evidence that not only the LRC-CTS, but also other computer-based videogames, are an effective enrichment strategy that elicits sustained engagement from captive NHPs (Washburn, 2015; for review and additional examples see Table 1). For example, investigators at the LRC tracked the activity budgets of 10 rhesus monkeys across several two-week intervals with, and without, 24-hour access to a videogame system [Washburn & Rumbaugh, 1992a]. During periods when videogames were available, the monkeys spent an average of 40% of a 24-hour day on task-related activities. Nearly all of the remaining time was spent sleeping or resting. In contrast, only 20% of the day was spent on task-related activities when the monkeys were provided with other forms of enrichment (e.g. grooming fleece, puzzle boards) instead of the videogames. Of particular relevance to assessing benefit to the animals' welfare, during provision of the other forms of enrichment, more time was spent performing relatively undesirable activities such as self-directed behavior (e.g. overgrooming), cage-directed behavior (e.g. shaking mesh), or stereotypy (e.g. pacing). More recently, Fagot *et al* [2014] demonstrated that, for nine baboons, access to touchscreen tasks decreased salivary cortisol levels [Fagot, Gullstrand, Kemp, Defilles, & Mekaouche, 2014]. Together, these studies demonstrate that computer-based videogame enrichment has both behavioral and physiological consequences that are consistent with improved well-being in NHP.

Over the past twenty-five years, researchers have demonstrated that monkeys can learn to complete computer-based games by eight months of age [Andrews, 1994], will play regardless of freely-available chow [Washburn & Rumbaugh, 1992a], and will play in order to obtain access to video of other monkeys [Andrews & Rosenblum, 1993; Washburn & Rumbaugh, 1994; Andrews & Rosenblum, 1994a]. Additionally, monkeys' engagement increases when there is a choice of task [Washburn, Hopkins, & Rumbaugh, 1991] and, despite dominance hierarchies, social housing has been shown to have a limited impact on individual play [Washburn, Harper, & Rumbaugh 1994; Fagot & Paleressompoulle, 2009; Fagot & Bonte, 2010]. Furthermore, while these studies evidence use in bonnet macaques (*Macaca radiata*), rhesus macaques (*Macaca mulatta*), and guinea baboons (*Papio papio*), additional studies demonstrated that computer-based games are engaging for pigtail macaques (*Macaca nemestrina*), squirrel monkeys (*Saimiri sciureus*), tufted capuchins (*Cebus apella*), and common marmosets (*Callithrix jacchus*; see Table. 1).

Despite compelling evidence over the past decades that monkeys' use of videogames has a range of benefits and is highly engaging, we know of no large primate facility that makes regular use of videogames in their husbandry, care, and enrichment program (as opposed to use as part of research programs). Nor does current policy or the Guide for the Care and Use of Laboratory Animals [National Research Council, 2011] contain recommendations based on the results of those studies. In fact, computer-based games are not mentioned in the Guide, nor in the most recent and extensive survey of environmental enrichment in US primate facilities [Baker, 2016]. In Baker's survey, the only reference to "cognitive" enrichment refers to provision of foraging devices, fleece boards, and puzzle feeders. Research facilities may use videogames for enrichment, but that is not apparent from the published survey of husbandry and enrichment practices. It is also true, however, that primate research programs in fields such as psychology, comparative cognition, and neuroscience often do employ videogames, or computer-based tasks, to measure aspects of cognition, learning, attention, memory, perception, etc.. In general, the convention in enrichment programs and in research regulation in the US is to not count research activities as part of enrichment. As a result, some provision of computer-based tasks to NHP would not be included in surveys accounting for husbandry or care-related enrichment practices.

The apparent discrepancy in between scientifically-informed best practices that draw from the empirical literature and actual community standards for captive animal care provided the impetus for the current study. In brief, primary obstacles to widespread implementation of complex cognitive tasks appear to include perception of high cost, high maintenance or effort to deploy and low recognition of benefit to the general population of animals. Previous studies have already provided a well-articulated rationale for the benefit of videogame systems to serve nonhuman primate enrichment. These studies have also provided practical guidance on how to employ these systems. Thus, further research demonstrating benefit in terms of animal welfare seems unlikely to address obstacles to implementation on a broad scale. What is missing, however, is systematic comparison of the cost for provision of the enrichment strategy and its actual use (or engagement) by the monkeys.

The study reported here provides such systematic comparison and uses an established method to place evaluation of videogames within a context for direct comparison to other commonly-used enrichment strategies.

In the present study, we directly compared monkeys' engagement with a common foraging device to the LRC-CTS videogame system across multiple time points. The central aim of the comparison was to measure not only amount of device use, but also cost of implementation for the enrichment strategies. To do so, we used the evidence-based approach for comprehensive assessment developed previously by our research group [Bennett, Corcoran, Hardy, Miller, & Pierre, 2010; Bennett et al., 2014]. Time on task is the primary measure of benefit that we have selected for use in cost:benefit evaluation because it was a measure direct interaction that can be readily collected and systematically compared across devices, species, facilities, and conditions. As such, it has high utility within an evidence-based approach to enrichment that is designed to maximize benefit for nonhuman primates within captive settings. Together, the cost:benefit analysis provides more generalizable results that can inform the selection of strategies in the refinement of current enrichment practices employed in a broad range of captive settings.

Methods

Subjects

Twelve adult male rhesus macaques (*Macaca mulatta*) participated in this study. The monkeys were housed at the Harlow Center for Biological Psychology (HCBP) and had extensive experience with the LRC-CTS prior to the start of these experiments. At the start of data collection, the monkeys ranged in age from 17 to 18 years and were housed individually within indoor enclosures (91 × 152 × 79cm) that provided visual, auditory, and olfactory access to each other. Six of the monkeys were mother-reared in social groups for the first six months of life, while six were reared with conspecific, age-matched peers in a nursery at the Laboratory of Comparative Ethology, National Institutes of Health Animal Center [Shannon, Champoux, & Suomi, 1998; see Novak & Sackett 2006 for detailed description and comparison of nursery-rearing conditions for additional detail on rearing procedures.]

Monkey chow (Purina 5038, Purina Mills, St. Louis MO) was provided twice daily, once in the morning and once in the afternoon, with water available *ad libitum*. Manipulatable enrichment objects were provided inside the cage (i.e., polypropene objects shaped as dumbbells, balls, frisbees; nylon rubber hedgehog; 4 inch nylon rubber Kong®). Objects were rotated every 2-weeks such that a specific object type was presented only two times over the course of one year. Animals were provided with fruit via their food hopper on Monday, Wednesday, and Friday; ice treats on Thursday; and foraging devices Monday through Friday. Additional foraging devices were not given on testing days during the experiment. All supplemental food items were delivered to the monkeys after cognitive tasks were completed for the day. The study was conducted in compliance with all regulations, including the University of Wisconsin-Madison Institutional Animal Care and Use Committee and the Guide for the Care and Use of Laboratory Animals [NRC, 2011]. This research adhered to the American Society of Primatologists principles for the ethical treatment of primates.

Materials

Computer-based videogames—Two apparatus configurations were used in this study. Both configurations employed the same software, manipulanda (joystick), and food pellet rewards. Monkeys' home enclosures had been slightly modified to permit them manual access to various apparatuses, puzzles, and games via a metal door (9 × 18cm) that could be removed during cognitive testing in order to allow the animals to use the videogame apparatus.

The first apparatus configuration was comprised of a polycarbonate cabinet (107 × 53 × 53 cm) that housed all of the equipment. The cabinet housed a computer (Dell 486, 66 mh), 15" monitor, pellet dispenser (Med Associates, St. Albans, Vermont), joystick (CH Products), relay box, and power supply. The joystick port (10 cm diameter) was centered under the monitor and contained a food well into which food pellets (Bio Serv 94 mg Grain-Based Diet Dustless Precision Pellets; Flemington, NJ) were dropped from plastic tubing connected to the pellet dispenser.

We developed a second test apparatus that was portable, relatively easy to build from commercially-available supplies, and flexible with respect to allowing videogame access for monkeys in a variety of home enclosure configurations. The second apparatus was created so that the cabinet housed just the computer, relay box and power supply. The monitor and pellet dispenser were mounted separately on a tall pole, and the joystick box with a food well was attached to the front of the monkey's home enclosure. The cabinet housing associated equipment (i.e., computer, power supply, relay box) was constructed of a commercially-available Rubbermaid™ rolling cart modified with polycarbonate sides to protect the electronic equipment

Finally, for the purpose of providing a full range of cost comparisons, the cost of a newer system we have developed with currently available—and less expensive—components is included here (contemporary system; Table 4). The newer system was not used for behavioral data collection in this study, but is included here in order to illustrate current cost options and systems. The older ("legacy") and newer ("contemporary") systems are identical from the perspective of delivering the computer-based tasks and in terms of the component parts with which the monkeys interact. In brief, the primary differences between the two systems includes the use of Raspberry Pi™ 3 computers and a standard 71" relay rack modified to roll on wheels. The Raspberry Pi™ computers currently retail for approximately $40, run open source software, and include all of the components necessary to provide output to an HD monitor; accept mouse, keyboard, and joystick input via standard USB; control a pellet-feeder via general input/output; and transmit data wirelessly via on board Wifi and Bluetooth™ support. They have the computing power to run not only newly developed tasks, but also emulators capable of simulating DOS environments in order to support running older software. The relay rack allows one unit to house all necessary components needed to provide joystick access to two enclosures simultaneously.

Foraging Device—The foraging device evaluated in this study, the Pipe Feeder, was selected because our prior research demonstrated that it elicits sustained manipulation more effectively than other commonly-used types of foraging devices [Bennett et al., 2014]. The Pipe Feeder was constructed of a PVC tube 17 cm long with an inner diameter of 3.81 cm, fitted with a 4.45 cm PVC cap on one end and a 10.16 cm chain on the other to attach the device to the cage. Holes of 1.27 cm diameter or 1.27 × 2.22 cm were drilled into the PVC tube to provide access to the food placed inside. The devices were hand-constructed with roughly equal numbers and distribution of holes across the surface of the pipe. Pipes were filled to capacity with a mix of popcorn and cereal in a 3:1 ratio (see below for detail).

Procedure

Behavioral data collection

Computer-based videogames: Monkeys were initially given three 100-min test sessions with two of the LRC-CTS tasks they had previously demonstrated high competence in performing: SIDES and Chase. The task used for joystick acquisition, SIDES, was obtained from the Language Research Center at Georgia State University and has been described elsewhere [Richardson et al., 1990; Rumbaugh et al 1989]. Briefly, SIDES is an auto-shaping procedure was used to elicit successively more difficult joystick responses on a contingent basis. Briefly, the SIDES task begins with monitor presentation of a black screen bordered by four 2.5 cm blue "sides" and a white circle (cursor, 1.5 cm) in the center of the screen. Joystick movement results in isometric movement of the cursor. "Hits," or correct trials, occur when the subject successfully moves the joystick-controlled circle into a side target. Correct trials are met with a rising tone (400–1000 Hz) and delivery of a banana-flavored chow pellet into a food well at the base of the joystick port. Increases in task difficulty occur as the number of sides (4, 3, 2, 1) decrease and, finally, as the size of the last side decreases (7.5, 5.0, 2.5 cm). In the subsequent CHASE task, correct responses require movement of the cursor so that it collides with a moving onscreen target. All of the monkeys were familiar with the tasks and had previously reached criterion. For SIDES, all animals could complete 95% of the trials at the highest level (2.5 cm) in each of 5 blocks of 200 trials. For CHASE, all of the monkeys were successful in completing trials in less than 5 seconds for 5 blocks of 200 trials.

To begin a session, the videogame apparatus was positioned in front of the cage so that the monkey could reach the joystick through an aperture in the cage front. The LRC-CTS is fully automated. Therefore, the experimenter left the room during test sessions and returned to end a test session. In the second phase of testing, monkeys were given three 300 minute sessions, the maximum allowed time in a care day to allow husbandry requirements at our facility. The extended sessions allowed for the evaluation of sustained videogame play. Finally, for an initial evaluation of whether monkeys' engagement was dependent on continued food reward, a subset of eight monkeys were given three 100-minute sessions with the Chase task with sound stimulus signifying a correct response, but without food pellet delivery (e.g., the pellet dispenser was emptied prior to the videogame session).

The LCR-CTS software saves a transcript of each test session that includes time-stamped performance data about each trial, thus permitting detailed analysis of the amount of time each monkey was engaged with the apparatus. Transcripts of all trials were analyzed to determine the proportion of the session the subjects were on task. In order to directly compare our results with previous data on monkeys' use of foraging devices [Bennett, et al., 2014], we determined the number of one-minute bins during which videogame trials occurred for (a) the initial 20 minutes of the session and (b) at 1-hour following access, minutes 60 to 80. For subsequent testing with 300-minute sessions we calculated the number of one-minute bins in which videogame trials were completed for: (a) the initial 20 minutes of the session; (b) after 1 hour, minutes 60 to 80; (c) after 2 hours, minutes 120 to 140; (d) after 3 hours, minutes 180 to 200; and (e) after 4 hours, 240 to 260. Interaction with the joystick videogame system was calculated in 1-min time bins (i.e., trials within each of the 20 bins over 0–20 min or 60–80 min, etc.) in order to directly compare interaction with the Pipe Feeder in the same time domain and with devices evaluated in our previous study (see below).

Foraging Device (Pipe Feeder): We evaluated monkeys' engagement with a foraging device by using a procedure identical to our previous assessment of this enrichment [Bennett et al., 2014]. Foraging device observations were not performed on days that videogame sessions were performed. Subjects were provided with Pipe Feeders affixed to their cages with swivel clips on three occasions, during which observers recorded manipulation of the devices at two time points: (a) the initial 20 minutes after device placement, and (b) at one hour following device placement, minutes 60 to 80. At each time point, observers recorded manual, pedal, or oral contact with the device as present or absent for each subject in each of the twenty 1-minute time bins. Data were recorded by observers to whom the animals were well-habituated because they were involved with normal daily delivery of enrichment devices and each session began with the normal husbandry routine for foraging device delivery. Behavioral coders entered the room sat in a central location in the room where they could see all animals under observation and their foraging devices. Coders left the room immediately after the initial observation period (20 min) and returned just prior to the start of the 1-hour observation period (60–80 min). Observers met high inter-rater reliability standards (Spearman's rho = .998).

Labor & Cost Calculations

Videogames: Cost analysis was divided into 3 major categories: 1) initial costs for purchase and manufacture of videogame apparatus; 2) cost of food pellets used in videogames; and, 3) costs related to husbandry (apparatus setup and take down).

Initial cost to assemble the computer-based game system included the cost of the computer and interfaces (computer or Raspberry Pi, joystick, relay, feeder, and power supply), cost of the joystick cart and associated equipment (cart, pole, hardware), and assembly labor. Cost of pellets was calculated using average number of trials per monkey for a 100-minute session, with one pellet dispensed per trial. The amount of time required for husbandry was recorded by a staff member performing pre-test set up and post-test take down for one videogame apparatus. Pre-test set up included checking that the monitor, pellet feeder, and joystick components were properly functioning and that the test parameters were entered correctly. Post-testing take down involved ending the test session and saving the data to an external disk for analysis.

Personnel times were recorded three times on two separate occasions, and the average number of minutes for set up and take down combined (mean = 3.20 ± 0.21 minutes) was used for labor calculations. Labor cost was calculated by using the average salary plus fringe benefits of existing staff that would normally perform this job function. Labor costs vary across facilities, therefore, in order to provide both more broadly generalizable data, but also direct comparison to our previous analysis of foraging devices [Bennett et al., 2010; Bennett et al., 2014], we calculated and include here both labor time and labor cost.

Foraging Device (Pipe Feeder): Cost analysis was divided into 3 major categories: 1) initial costs for purchase of materials and labor to manufacture the devices; 2) cost of foods used in the foraging devices; and, 3) costs related to husbandry (food preparation, device placement, and cleaning).

The cost and amount of time required for husbandry was assessed in the same manner as described above for the videogame apparatus. In brief, actual labor time (in minutes) was recorded by 2 staff members performing each of the husbandry tasks related to the study: preparing food, cleaning the preparation tools and area; and filling, attaching, removing, and cleaning each device. The time for each task was recorded on 3 occasions by each person, with the average used for subsequent calculations. Forage foods consisted of popcorn and a mix of cereals purchased in bulk: Bunch O' Krunch, Cocoa Munchies, Fruit Whirls, Happy Shapes (Hospitality brand, Gilster- Mary Lee, Chester, IL) and Apple Zingers (Malt-O-Meal; Lakeville, MN). Devices were cleaned as follows: If necessary, devices were soaked in a dishwashing soap solution to loosen and remove remaining food particles. All devices were then rinsed in a bleach solution and sanitized with two wash cycles in a high-temperature dishwasher (Avenger HT 208/230/1, Jackson, Barbourville, KY).

Data analysis

Following an initial analysis that indicated no significant differences between mother- and peer-reared monkeys, we proceeded to a within-subjects design for each of the three experiments. One subject never made contact with the Pipe Feeder and was removed from the analysis. For the comparisons of engagement with the foraging device and the joystick tasks, we used one-way repeated measures analysis of variance (ANOVA) at each of the two time periods. For the extended-length joystick sessions, we used a one-way repeated measures ANOVA to assess differences in frequency of engagement with the SIDES task at five time points. Comparisons of time on task during conditions with and without food incentives were also subjected to repeated measures ANOVA. Fishers PLSD was used for all *post-hoc* comparisons.

Results

Videogames vs. Foraging Device

The videogames and the foraging device were equally effective at eliciting manipulation during the initial observation period. Mean time intervals on task for the three conditions ranged from 18.36 to 18.85 minutes out of the possible 20 minutes (See Figure 2A). There was no significant difference between tasks in manipulation during the initial interval, $F(2,10) = 0.13$, $p = .88$.

By contrast, the videogames proved to be far more effective than the Pipe Feeder in promoting sustained manipulation during the time period 1 hour after device placement (i.e., 60–80 min). Monkeys were engaged with the Sides and Chase tasks for an average of 17.33 and 15.30 minutes respectively at 1 hour, whereas manipulation of the foraging device dropped to an average of 2.82 minutes (See Figure 2B). Repeated-measures ANOVA indicated significant differences in manipulation time between tasks, $F(2,10) = 43.93$, $p < .0001$, and *post-hoc* tests revealed that manipulation of the joystick was significantly higher for both tasks than for the foraging device ($p < .001$). Means for each of the three tasks at both time points for each monkey are provided in Table 2.

Extended-length videogame session

Time on task for videogame SIDES task varied across the time periods during the extended sessions, $F(4,10) = 7.562$, $p < .0001$. Post-hoc tests indicated that the amount of time spent on the SIDES task was significantly higher during the initial time period than during the any subsequent time periods, 2 hour ($p = .03$); 3 hour ($p = .0001$); and 4 hour ($p < .0001$). Similarly, manipulation during the period 1 hour after placement of the apparatus was higher than the 3-hour ($p = .007$), 4-hour ($p = .003$), or 5 hour ($p = .003$) time periods. The final two periods were not different from each other (see Figure 3). Individual subject means for each of the time periods are provided in Table 3.

Pellet-free sessions

Comparison of monkeys' use of the joystick system during food pellet vs no pellet conditions demonstrated that the food was necessary to elicit sustained engagement. Videogame play was significantly higher for the pellet condition (mean = 19.00 ± 1.98 minutes) than for the pellet-free condition (mean = 4.50 ± 1.75 minutes) at the initial time period, $F(1,7) = 177.50$, $p < .0001$. Similarly, at the 1 hour time period there was significantly more videogame play in the pellet condition than in the pellet-free condition, $F(1,7) = 1937$, $p < .0001$ (see Figure 4).

Cost analysis

Estimates for the initial and ongoing costs of providing nonhuman primates with the videogame system and several types of foraging devices are provided in Table 4. The initial cost of purchase and construction of either of the videogame systems greatly exceeds that of the foraging devices. The older "legacy" version of the videogame system costs US$1650 for a single unit that can be used by one monkey at a time. A contemporary version of the videogame system costs US$1,869 for a duplex unit that can be used by two monkeys at a time, or US$935 for a single animal. By contrast, the cost of foraging devices ranges from US$5.75 for the in-house constructed Pipe Feeder used here to US$139.00 for a more expensive commercially-available device (see also Bennett et al., 2014 for additional detail). Estimated supply costs per use were also much higher for the videogame system (US$1.55) than the foraging devices (range: US$0.07 to US$0.21); however, these figures assume that the subjects are highly engaged with the videogames and receive an average of 500 pellets per session. Labor time was much more comparable, with 2.4 minutes for the Pipe Feeder and 3.2 minutes for a videogame session. Overall, for a single session for one monkey the cost of the two enrichment strategies evaluated in this study was US$2.56 for the videogame and US$0.94 for the Pipe Feeder.

Discussion

The findings of this evaluation of enrichment strategies demonstrate that the videogame system is more effective in promoting monkeys' sustained engagement in comparison to their engagement with commonly-used foraging devices. Monkeys interacted with the videogame system and the foraging device at high levels during the first twenty minutes of exposure. After one hour, however, the Pipe Feeders went largely untouched, whereas videogame play continued at levels comparable to the initial twenty minutes. Even four hours after being presented with the videogame system, the monkeys spent more than twice as much time engaged in task-directed activity than they did after one hour of exposure to the foraging device. During the extended-length testing sessions, nearly all of animals averaged well over 1,000 trials, with some animals completing as many as 1,889 trials in 300 minutes. Furthermore, our results demonstrate that the videogame system can elicit high levels of engagement in animals that are well habituated to the device. In other words, the engagement does not depend on novelty. It remains for future study to determine whether, and at what point in training, monkeys who are naïve to the videogame system would show levels of engagement comparable to those of experienced animals. Our findings are consistent, however, with previous results in another population of monkeys and with a large body of literature that employs computerized joystick or touchscreen tasks for cognitive assessment in nonhuman primates [Washburn 2015; also see Table 1]. Thus, there is high likelihood that the current results would generalize to other populations.

The results reported here clearly demonstrate that the videogame system has the capacity for eliciting sustained engagement. Although these computerized tasks incorporate features of food-based and sensory enrichment, their primary value comes from providing cognitive engagement through psychological puzzles and hand-eye coordination, and are therefore appropriately classified as "occupational enrichment" [Bloomsmith, Brent, & Schapiro, 1991]. This form of enrichment is thought to benefit the psychological well-being of captive nonhuman primates by supplying an outlet for evolved cognitive skills to be exercised while solving problems [Clark, 2011]. Cognitive challenges are typically only seen as enriching when the skill level of the animal is appropriately matched to the level of task difficulty. The computerized system used herein is well-suited for this, since the testing software can automatically record an animal's performance and adjust the difficulty up or down on subsequent trials to meet the animal's current skill level.

The videogame system clearly has many benefits in terms of occupational enrichment for monkeys. The primary purpose of our assessment, however, was not only to evaluate benefit in terms of monkeys' engagement, but also to directly compare engagement and cost relative to other enrichment devices commonly used in facilities housing nonhuman primates. We have previously proposed more systematic and widespread use of a cost:benefit framework for direct comparisons that can facilitate evidence-based decision-making in environmental enrichment. Our framework places enrichment strategies within the context of a value matrix in which the most desirable strategies are those with high benefit and reasonable costs (Figure 1C). Thus, in order to determine the videogame system's position on the value matrix, it is not only the associated benefit in terms of engagement that must be considered, but also the associated costs for implementation.

As expected, comprehensive cost analysis demonstrated that the videogame system is more expensive to implement on a per session basis than any of the commonly-used foraging devices. Initial construction and equipment costs are higher for the videogame system than for other devices we have analyzed (see Table 4). Initial costs and ongoing implementation costs are central to selection decisions for environmental enrichment and both are included in our model for cost analysis. The implementation costs for the videogame system are roughly twice that of foraging devices on a "per use" basis (i.e., a single session, enrichment delivery, or presentation of a device). The difference is largely attributable to supplies rather than labor. In short, the types of food that are typically used in foraging devices are less expensive than the specialty food pellets used for the automated pellet dispenser in the computer-based apparatus. The amount of staff time needed to deliver an enrichment opportunity via the videogame system (3.2 min) is also somewhat higher than that involved in prepping food foraging devices (2.4 min).

Perhaps the biggest obstacle facing widespread implementation of computer-based enrichment systems is the initial construction cost. Although certainly higher than simple foraging devices, the exact cost will vary by need, as the apparatus is highly customizable. For example, in a series of experiments, Washburn and Rumbaugh [1992b] found minimal (if any) declines in performance or productivity when manipulating various system parameters like computer type, monitor type, monitor size, joystick brand, joystick size, pellet size, and pellet type. Once monkeys are well trained in the task paradigm, the specific configuration of the system's components appears to be flexible, as demonstrated by our own monkeys rapidly reaching established performance levels when introduced to slight changes in apparatus configuration.

The robust nature of this test paradigm gives investigators the freedom to build in a way that suits the specific needs of their research subjects, cage design, and budget. The system generally does not require cage modification but this may depend upon the environment or facility considerations. Although the initial cost of purchase will likely exceed that of virtually all other types of enrichment devices, steps can be taken to make the system affordable. State-of-the-art hardware is neither necessary nor recommended, so building with used computers and monitors can considerably reduce the projected price, as is demonstrated by the cost analysis of the contemporary system that we have developed. We have found that these automated systems have excellent longevity, as long as appropriate precautions are taken to protect the wires and hardware from moisture and the hands of curious monkeys [See Washburn and Rumbaugh, 1992b for a thorough discussion of the strengths and pitfalls of testing with automated joystick-based apparatuses]. Moreover, these devices are transportable, and devices can be rotated between multiple subjects within a day, thereby reducing the total number of units needed to provide enrichment for a population of NHPs. Finally, it is worth noting that animals housed in social groups may require fewer individual systems [Fagot & Paleressompoulle, 2009; Fagot & Bonte, 2010].

In addition to the high initial cost, our results demonstrate greater ongoing supply costs for the videogame system than for the various foraging devices examined. This is mostly due to the fact that the specially-formulated 94mg reward pellets are more expensive than the commonly-available items like popcorn and cereal used in the Pipe Feeder. Given that Washburn and Rumbaugh [1992b] found no differences in performance or productivity when the pellet size was varied between 45, 97, 190, and 300mg, costs can be reduced by using the smallest (and therefore least expensive) pellets available. Finally, it is possible that the automated feeders could be modified to deliver less expensive alternatives to commercially-available pellets.

Nutritional Considerations

Enrichment methods that employ food are often perceived as sources of uncontrolled dietary variation with potential for adverse effects on research. We propose several potential options for researchers concerned with the nutritional consequences of pellet consumption associated with computer-based tasks that use pellets as reward. The most obvious solution is to eliminate food altogether—opting instead for nonnutritive rewards like video-stimulation. For example, Andrews and Rosenblum [1993] found that rewarding successful trials with brief access to a live video feed of conspecifics was a sufficient incentive to elicit sustained engagement with the videogame system from their sample of five bonnet macaques. A similar study by Washburn and Hopkins [1994], however, did not replicate these findings with two rhesus macaques. The contradictory results led the authors to note that variables such as individual preference, rearing history, training history, and social arrangement must be considered when assessing and predicting the efficacy of nonnutritive rewards. The discrepancy could also be attributed to differences in pellet size and the length of the video reward [Andrews & Rosenblum, 1994a]. Although our monkeys do not seem interested in playing videogames in the absence of food pellet rewards, further research could determine whether naïve animals can acquire and perform the task without food incentives.

A second option is to alter the reward schedule in order to reduce the total number of pellets awarded for a set of responses. In the present study monkeys received a pellet after every successful trial, except in the no-pellet test sessions. Although a continuous reinforcement schedule of one pellet per correct response is likely ideal for training, once the task is mastered the monkeys could be transitioned to a partial reinforcement schedule with reward delivery after several trials or a variable number of trials. Preliminary testing with the monkeys in this study suggests that the number of trials performed meets or exceeds baseline levels when rewards are administered after two correct responses. Further testing will be necessary to ascertain the optimal reinforcement schedule for reducing caloric intake and ongoing supply costs without compromising the efficacy of the system as an enrichment strategy [Ferster & Skinner, 1957].

Conversely, a third option would be to provide animals with the videogame system for extended periods of time so that they can earn most, or even all, of their daily caloric requirement via the computer-based system. The pellets used by our lab have a nutritional profile comparable to the chow biscuits eaten by our monkeys each morning and afternoon (Purina 5038 Monkey Diet). Supplemental chow could be provided after game sessions in order to maintain the animal's total daily caloric allowances. An ideal strategy for delivering additional food could involve crumbling chow bits onto a turf board, which has been shown to greatly increase the amount of time spent engaging in foraging and consummatory behaviors [Bayne et al., 1992]. Using this method, the monkeys would be able to apply their cognitive, perceptual, and fine motor skills to accomplish a variety of tasks and acquire food in ways that resemble the demands of the natural environment more closely than simply removing chow biscuits from a food hopper at feeding time. Although this method would certainly more labor intensive than many alternatives, the comprehensive cost remains to be evaluated. For example, it is possible that reductions in labor time associated with feeding chow could partially offset the cost of delivery food via an automated system.

Implications for future application, decision-making, and policy-relevant consideration

Our findings add to over two decades of empirical studies by a number of laboratories that together have demonstrated the successful use of computer-based game systems to promote sustained non-social cognitive engagement for laboratory housed macaques. The main objective of the study, however, was to also address factors that contribute to the gap between the scientific evidence and the failure of this enrichment strategy to become a common and widespread practice in the broad range of facilities that house captive primates. Thus, the broader significance of the work lies in the application of a systematic approach to fully assess cost and relative value.

As in our previous work [Bennett et al., 2014], in Table 5 we provide an illustration to show the projected 1 year cost to provide 100 monkeys for each of the enrichment strategies we have evaluated. We selected 100 animals and 1 year as an initial unit that could be multiplied or otherwise adjusted in order to estimate costs, compare different strategies, and inform decisions. The point of the table is to provide an accessible example for estimating the cost to provide particular types of enrichment at a facility level because this is the level at which decisions are commonly made by facility managers and others ultimately charged with budgeting and managing care costs. The table is not meant to cover every situation or particular housing configuration. Rather, it is a model that can both inform further analysis at the level of an individual facility, and also provide information that is currently unavailable for consideration of impact and feasibility in discussions of policy recommendations for continuing advances in captive animal care.

Table 5 illustrates how the cost calculations can be used to estimate the difference between strategies that result in relatively low engagement by the monkeys versus those that provide for higher engagement. For the purpose of illustration, we show the cost of foraging devices delivered once per week (low engagement), those delivered each day, and the videogame system offered each day. Taken together, the cost and engagement data can also provide a measure of relative value. While the videogame system has a higher cost, the fact that it provides opportunity for sustained, contingent, and cognitively-engaging activity means that it also has higher relative *value*.

Overall, the benefit and cost evaluation and comparison reported here illustrates why the value matrix perspective can be informative for choices about primate enrichment. As shown in Table 5, if the videogame system is considered only in terms of relative cost, it appears to be a poor choice for widespread implementation. By contrast, when considered within the value perspective that incorporates both a quantitative index of sustained use by the monkeys and consideration of the literature that underscores the value of providing opportunities for more complex cognitive engagement, the videogame system appears to be a high value choice for environmental enrichment programs. At the same time, it is also critically important to note that videogame systems may not be suitable for all facilities and may not be compatible with the needs of some kinds of research. Thus, the balance of research objectives, budgetary constraints, and other factors are other central aspects of the cost:benefit analysis that drives decisions.

In sum, while the videogame system has a higher cost, another way to view the cost—or the costs of environmental enrichment and behavioral management more generally—is from the perspective of placing psychological, cognitive, and behavioral needs on par with somatic, clinical, and other needs that are routine and expected costs inherent in primate care. Thus, we would note that within the context of captive primate husbandry, the overall cost of the videogame system is well within the range of other necessary equipment and care costs. For example, standard quad-cage housing for indoor-housed monkeys ranges from approximately USD$8,500 to over $16,000. By extension, housing for 100 monkeys might range from $425,000 to $1M. In other words, placed within the appropriate context of costs for other requisite equipment for best practices in animal husbandry rather than in comparison only to other enrichment devices, the cost of videogame systems to provide enrichment and cognitive engagement is relatively low.

As it currently stands, there is very little in the literature on enrichment and animal care that specifically addresses the balance of costs associated with various aspects of captive animal care and housing. We believe that the comparison of enrichment cost to that of housing- or to any other cost associated with husbandry and care, clinical medicine, or regulatory compliance is a reasonable approach to considering current practices. The perspective emphasizes that enrichment and psychological well-being should receive high priority in decisions. At the same time, very real economic considerations necessarily play a major role in decision-making. Thus, increased costs in one aspect of care will likely need to be accompanied by compensatory decreases in some other aspect of the animal program. What we are suggesting here is that costs related to directly providing for animals' psychological welfare should receive explicit consideration and equivalent priority in analysis and balance of competing costs, including those costs associated with regulation- and accreditation-related activities whose rationale rests on protecting animals' welfare.

To our knowledge, there is no commonly accepted range, or community standard, for the proportion of husbandry costs that are designated for primate enrichment. This is somewhat surprising given the central importance of nonhuman primate psychological welfare and continued growth in community and regulatory emphasis on the need for best practices to provide meaningful enhancement of welfare. It remains for future study to provide initial data on quantitative ranges of investment in nonhuman primate environment enrichment. Such analysis must account for a number of factors that influence costs, among them regional variation, types of facility, types of research, housing. Nonetheless, basic ranges and descriptive information about proportional investment in equipment, labor, and supplies are likely to inform and enhance continuing progress in identifying community standards, best practices, and policy grounded in empirical science.

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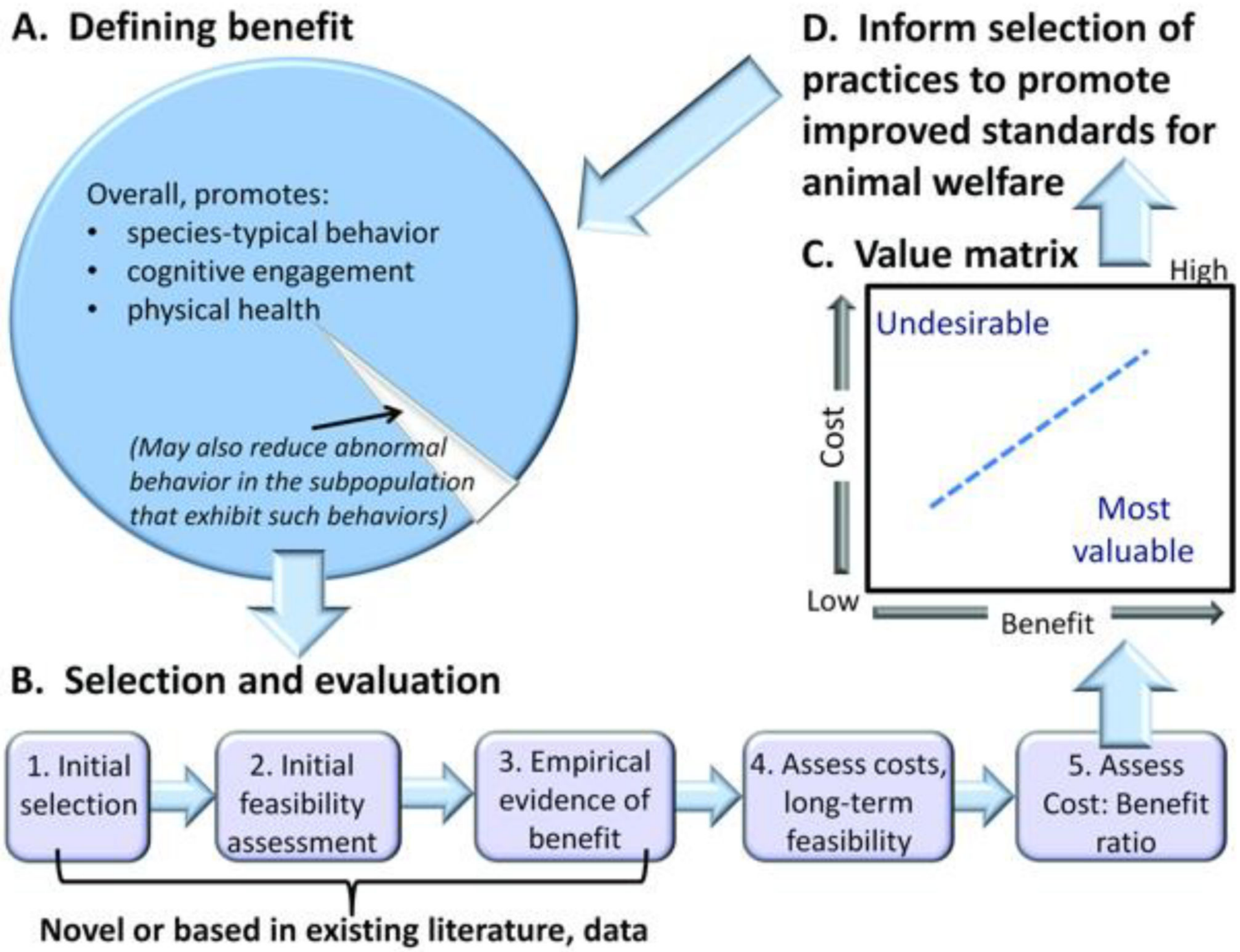

Figure 1.
Illustration of model process for assessment of environmental enrichment strategies (reproduced from Bennett et al., 2014).

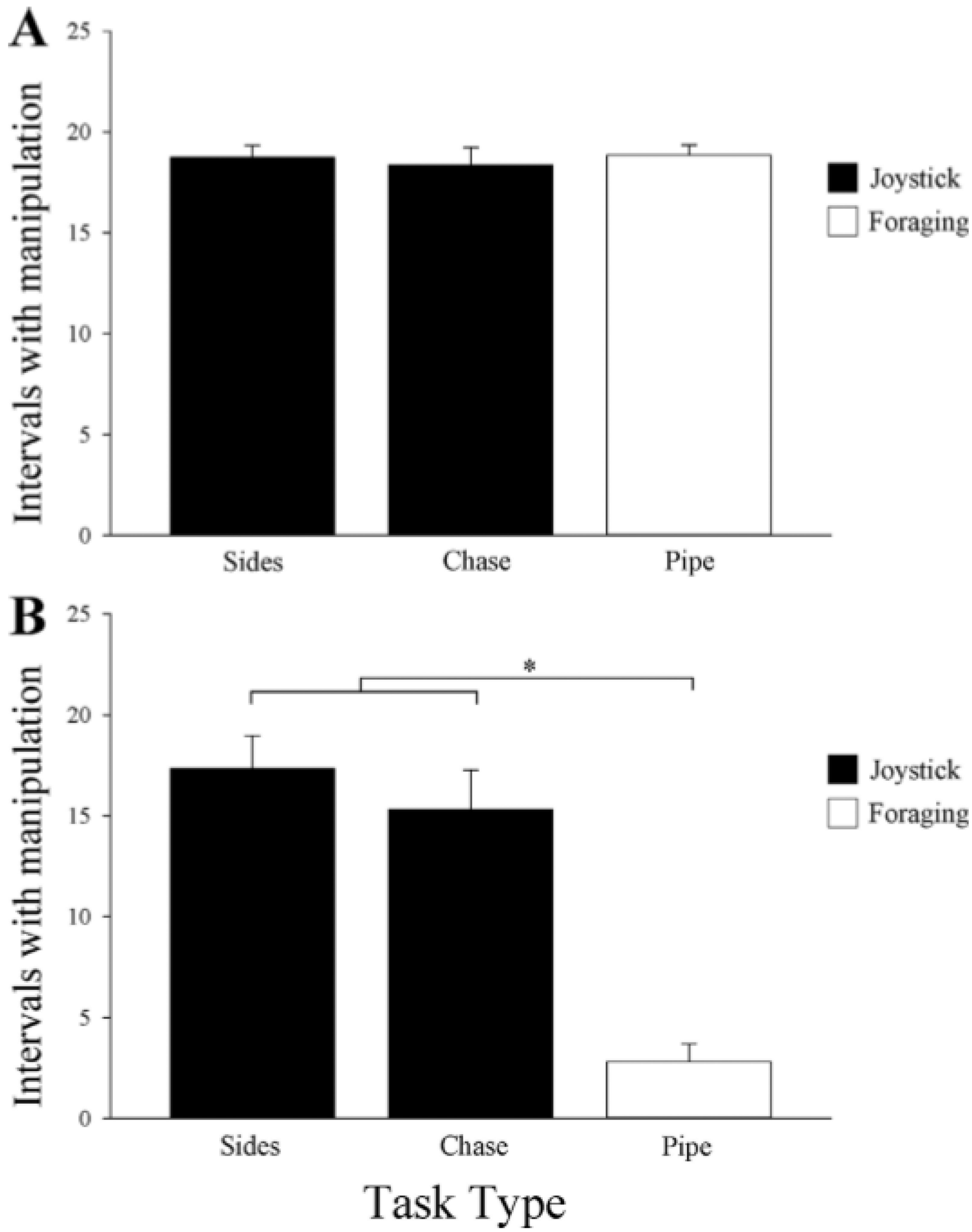

Figure 2.
Number of intervals (mean ± SEM) with manipulation for two videogame tasks and a foraging device during: (A) the initial observation period (0–20 min); and (B) the observation period 1 hour after device placement (60–80 min). Post-hoc tests showed that manipulation of the videogame system was significantly higher for both tasks in comparison to manipulation of the foraging device at the 1-hour observation period (* $p < .05$).

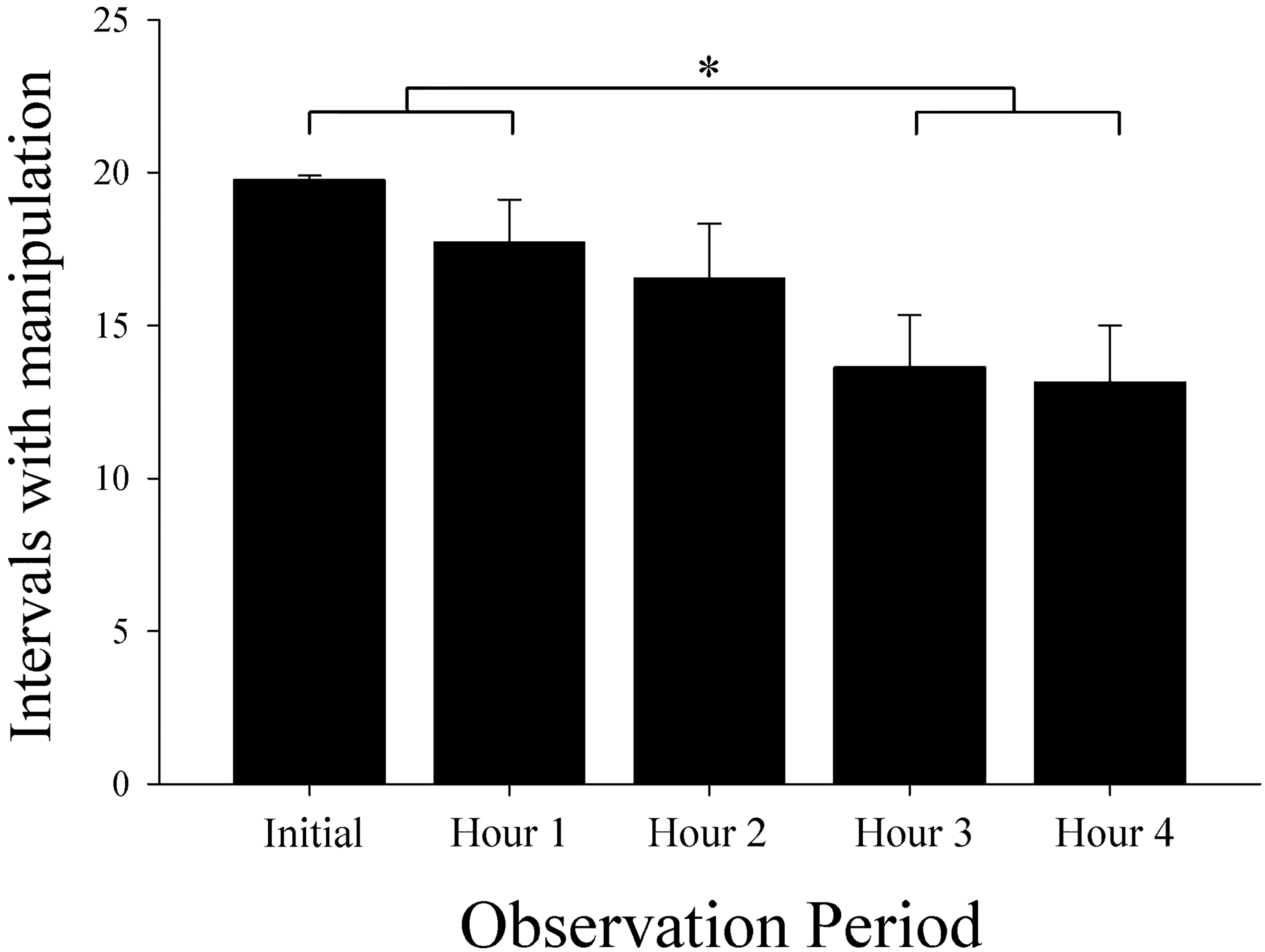

Figure 3.

Number of intervals (mean ± SEM) with manipulation for the videogame Sides task across five observation periods. Symbols refer to significant differences in manipulation between time periods (*$p < .05$).

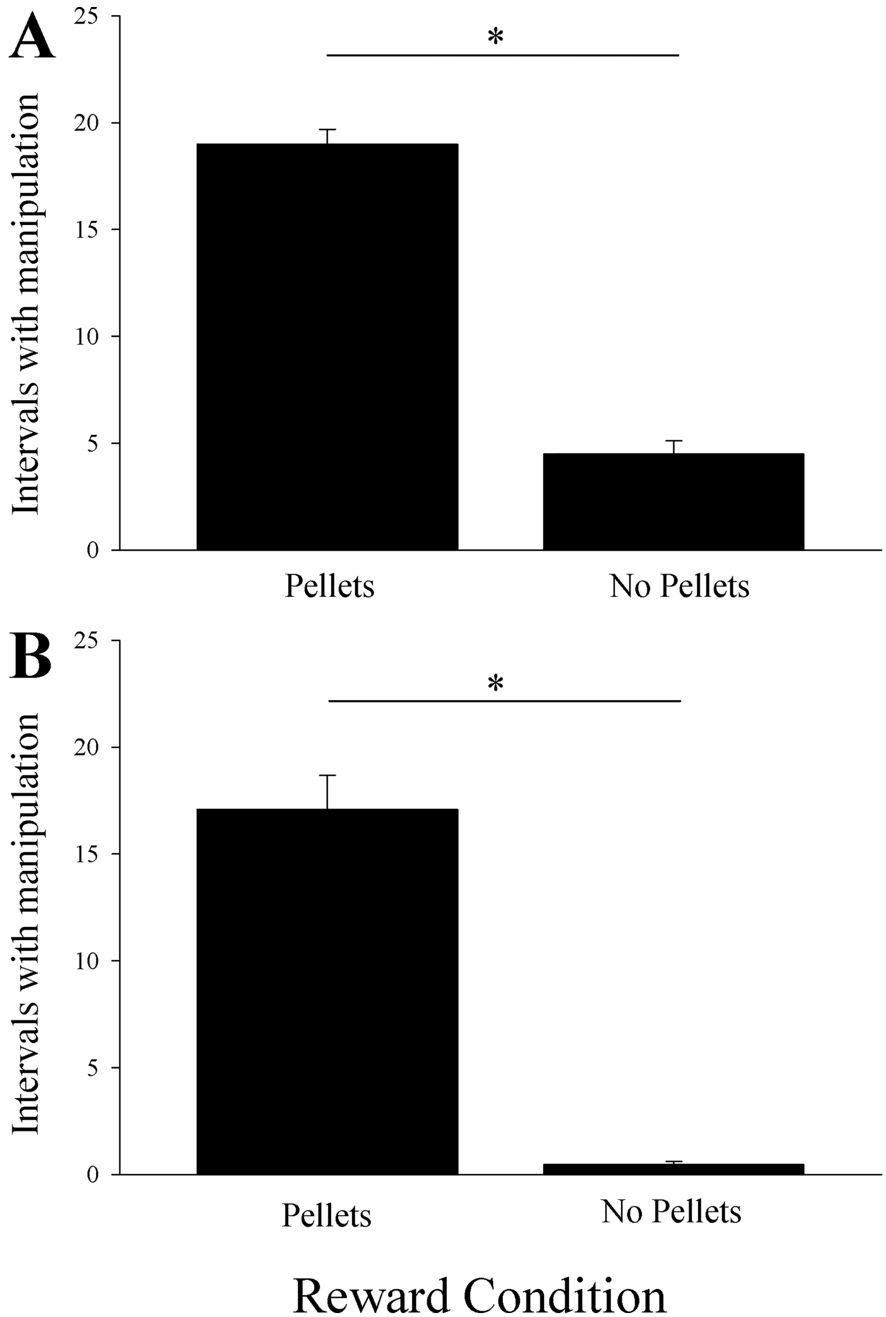

Figure 4.

Number of intervals (mean ± SEM) with manipulation for the videogame Chase task under two reward conditions during: (A) the initial observation period (0–20 min); and (B) the observation period beginning 1 hour after the session start (60–80 min). Manipulation of the videogame system was significantly higher at each time period when trials were rewarded with a banana pellet (*$p < .05$).

Table 1

A brief literature review of studies relevant to the use of videogame tasks in monkey enrichment.

Authors	Year	Species	Age Description	N	Manipulation	Summary of Findings
Washburn D.A., Hopkins W.D., and Rumbaugh D.M.	1991	Rhesus macaque (*Macaca mulatta*)	7 years	2(m)	Various manipulations allowing choice of videogame task vs assigned videogame task.	Increased response time, Increased response latency, and decreased % correct when task assigned.
Washburn D.A. & Rumbaugh D.M.	1992a	Rhesus macaque (*Macaca mulatta*)	3–9 years	10(9 m, 1 f)	(1) 2-week intervals with and without continuous access (2) Access to chow following testing vs chow continuously available. (3) Two conditions, both allow for choice of videogame task. One condition allowed the option to receive 1 pellet every 12 seconds for 1 minute; The other condition allowed the option to receive 1 pellet every 12 seconds for 30 minutes.	(1) 40% of day spent on task-related activities as compared to 20% when only provided with standard enrichment. Decreased stereotypical behavior during continuous access period (2) Reduced number of trials when chow available; Large amounts of play (280 trials/day) still observed despite availability of chow. (3) In the first condition the free pellet option was reliably preferred. In the second condition the free pellet option was significantly avoided.
Washburn D.A. & Rumbaugh D.M.	1992b	Rhesus macaque (*Macaca mulatta*)	3–9 years	10(9 m, 1 f)	Various manipulations of system parameters (i.e. monitor type, joystick size, etc.	Minimal to no decline in performance or productivity due to any manipulation of system parameters.
Andrews, M. W. & Rosenblum, L. A.	1993	Bonnet macaque (*Macaca radiata*)	Adult Male	5(m)	No reward vs 10-sec conspecific video reward vs 196mg food pellet reward	No difference between pellet-reward weeks and live-video-reward weeks. No reward resulted in significantly less play.
Andrews, M. W.	1993	Squirrel monkey (*Saimiri sciureus*)	5.5 years	1(m)	N/a, case study examining feasibility of joystick videogame use by a squirrel monkey.	The squirrel monkey successful learned to operate the joystick apparatus and was able to complete tasks with both fixed and moving target stimuli.
Washburn D.A. & Hopkins W.D.	1994	Rhesus macaque (*Macaca mulatta*)	7 years	2(m)	(1) No reward vs 97mg food pellet reward vs 30-sec conspecific video reward. (2) Pellets alone vs pellets +video reward. (3) Choice between free video and 3 tasks.	(1) Significantly more trials performed for pellets than for videotape, significantly more trials performed for video tape than for no reward. (2) No difference between conditions. (3) Free video was selected significantly less frequently than all joystick tasks.
Andrews, M. W. & Rosenblum, L. A.	1994b	Bonnet macaque (*Macaca radiata*)	Adult Male	5(m)	Restricted access duration across different times of the day vs unrestricted access.	Significantly different levels of engagement depending on time of day. Joystick play peaked in late-mid afternoon regardless of whether or not access was restricted.
Andrews, M. W.	1994	Bonnet macaque (*Macaca radiata*)	3.5–7.5 months	1(m)	N/a, case study examining joystick task acquisition in an infant monkey.	Infant monkey exposed to incremental training on a joystick apparatus at 3.5 months age acquired the ability to maintain contact with a small moving target by 7.5 months age.
Washburn, D. A., Harper, S., & Rumbaugh, D. M	1994	Rhesus macaque (*Macaca mulatta*)	10 years	2(m)	Pair housing vs single housing.	Pair housing did not alter levels of videogame productivity or performance.
Leighty, K.A. & Fragaszy, D.M.	2003	Tufted capuchin (*Cebus apella*)	5–7 years	4(m)	Examination of joystick task acquisition with inverted vs isomorphic cursor movement.	All 4 capuchins acquired the task. Inversion of joystick controls did not affect the overall rate of acquisition.
Spinelli, S., Pennanen, L., Dettling, A. C., Feldon, J., Higgins, G. A., & Pryce, P. R.	2003	Common Marmoset (*Callithrix jacchus*)	2–12 years	14(8 m, 6 f)	N/a, validation of marmoset acquisition of a number of touchscreen tasks.	Subsets of the entire sample were allocated to, and successfully trained in, a variety of working memory and motivation related tasks.

Authors	Year	Species	Age Description	N	Manipulation	Summary of Findings
Mandell, D. J. & Sackett, G. P.	2008	Pigtail macaque (*Macaca nemestrina*)	3–7 months	18(13 m, 5 f), 7(5 m, 2 f)	Testing touchscreen task acquisition between two groups of infant monkeys, one 90-days of age, the other 180-days.	23 animals successfully completed training, both groups learned to touch a stimulus on 90% of trials after approximately 24 days of training.
Fagot, J. & Paleressompoulle, D.	2009	Guinea baboon (*Papio papio*)	22 years	9(6 m, 3 f)	N/a, Case study examining videogame play in social groups.	Motor, perceptual, and cognitive performance measures were obtained across all animals despite group housing and established dominance hierarchies.
Fagot, J. & Bonté, E.	2010	Guinea baboon (*Papio papio*)	0.3 – 32.2 years	26(9 m, 17 f)	(1) Descriptive examination of use in a large social group. (2) The influence of the videogame system on troop activity budget.	(1) One million interactions with the interface across 85 days. 75% of the group learned to interact with the touch screen. Younger animals tended to interact the most. (2) Presence of the test system did not change the nature of social interactions or promote social conflicts.
Gazes, P. R., Brown E. K., Basile, B. M., & Hampton, R, R.	2013	Rhesus macaque (*Macaca mulatta*)	4 – 8 years	24(m)	Performance comparison between laboratory and semi-free ranging monkeys.	No significant difference between housing settings in the number of errors to reach criteria, the effect of difficulty level, or learning rate across psychophysical, classification, transitive inference, and memory tasks.
Fagot, J., Gullstrand, J., Kemp, C., Defilles, C., & Mekaouche, M.	2014	Guinea baboon (*Papio papio*)	2.1 – 27.5 years	9(m)	Manipulated access to videogame systems and measured impact on cortisol and activity budget.	Cortisol significantly decreased with videogame access. Subtle effects on behavior; significantly decreased resting, increased locomotive and social behavior, and some evidence for decreased stereotypy with videogame access.
Calapai, A., Berger, M., Niessing, M., Heisig, K., Brockhausen, R., Treue, S., & Gail, A.	2016	Rhesus macaque (*Macaca mulatta*)	4 – 12 years	11(m)	N/a, primarily a descriptive methods paper for home cage-based touchscreen training with a juice reward.	Successful method of home cage-based training across multiple housing configurations. Demonstrates the use of a juice reward, which is more commonly used in behavioral neuroscience research.

Table 2

Mean number of intervals with device manipulation for each monkey for all three tasks at the initial and 1-hour time intervals.

	Initial (0–20 min)			1-hour (60–80 min)		
Subject	Sides	Chase	Pipe	Sides	Chase	Pipe
S1	19.67	20.00	20.00	20.00	20.00	5.33
S2	18.33	19.00	19.33	15.00	12.33	1.33
S3	19.67	20.00	19.00	19.67	20.00	5.67
S4	20.00	20.00	16.00	20.00	20.00	0.00
S5	17.33	14.33	19.67	18.33	13.67	4.67
S6	13.33	19.33	20.00	16.67	20.00	0.00
S7	19.67	18.33	20.00	20.00	7.67	0.00
S8	19.67	19.67	15.00	20.00	19.33	0.67
S9	20.00	20.00	19.33	19.67	19.67	3.00
S10	19.67	20.00	19.33	19.67	15.67	8.67
S11	18.67	11.33	19.67	1.67	0.00	1.67
Mean	18.73	18.36	18.85	17.33	15.30	2.82
SD	1.97	2.87	1.70	5.45	6.54	2.90

Note. Manipulation was coded with a “0/1” coding scheme for each 1 min bin beginning at each time point for the following 20 min period.

Table 3

Number of intervals with videogame trials for the SIDES task at multiple time points

Subject	Initial (0–20 min)	1-hour (60–80 min)	2-hour (120–140 min)	3-hour 180–200 min	4-hour (240–260 min)
S1	19.67	20.00	20.00	20.00	20.00
S2	20.00	19.00	20.00	20.00	20.00
S3	20.00	19.67	19.67	19.33	20.00
S4	20.00	20.00	20.00	20.00	16.33
S5	20.00	20.00	19.67	14.67	14.00
S6	20.00	20.00	17.67	12.33	10.00
S7	20.00	20.00	20.00	6.00	12.33
S8	20.00	20.00	18.67	12.33	6.67
S9	20.00	19.33	14.33	9.00	12.67
S10	19.00	10.33	11.00	11.67	12.67
S11	18.67	6.67	1.00	4.67	0.00
Mean	19.76	17.73	16.55	13.64	13.15
SD	0.47	4.65	5.92	5.68	6.14

Note. Manipulation was calculated with a “0/1” coding scheme for each 1 min bin beginning at each time point for the following 20 min period.

Table 4

Ongoing and initial supply costs per device.

Device	Labor Total (min)	Ongoing Costs			Initial Device Cost
		Labor[1]	Supplies	Total	
Legacy Videogame System	3.2	$1.01	$1.55[2]	$2.56	$1650.00[3]
Contemporary Videogame System	3.2	$1.01	$1.55[2]	$2.56	$935[4]
Pipe Feeder	2.4	$0.76	$0.18	$0.94	$5.75
PES Frame[5]					$69.00
Food Feeder	2.4	$0.76	$0.18	$0.94	$59.50
Food Feeder (Study 2)	2.9	$0.92	$0.21	$1.13	$59.50
Treat Dispenser	2.6	$0.81	$0.12	$0.93	$70.00
Combination Panel	2.6	$0.81	$0.18	$0.99	$45.00
Challenger Ball	2.5	$0.78	$0.16	$0.94	$39.50
Paint Roller	2.1	$0.67	$0.07	$0.74	$9.27

[1] Labor rate = $19/hr

[2] Supplies for videogame assumes average of 500 pellets in 100 min session

[3] Estimates reflect current prices for computer, joystick, pellet feeder and interface.

[4] Estimates reflect current prices for a system that provides access to two enclosures at once, therefore the total system cost has been divided by two for a per monkey cost assessment.

[5] Devices in shaded area were assessed in Bennett et al., 2014 and are presented here to allow for convenient comparison of the videogame system and Pipe Feeder to other enrichment strategies.

Table 5

Illustration of how cost projections could be calculated to estimate comparisons of different strategies Shown below is the estimated cost to provide 100 monkeys with each enrichment strategy for one year.*

	Device and frequency	Initial device cost	Food supplies for 1 year	Labor (hours per week)	Estimated total (without labor)
Low engagement	Pipe with forage food 1x/week	$575.00	$936.00	4.00	$1,511.00
Higher engagement	Combination Panel with forage food 5x/week	$11,400.00	$4,680.00	21.67	$16,080.00
Higher engagement	Computer-based videogames delivered 5x/week via contemporary system	$16,830.00	$19,500.00	26.67	$36,330.00

*Note: Labor and cost estimates do not include the full range of activities required to implement environmental enrichment. For example, the cost of equipment related to food preparation and storage and the cost of cleaning supplies and equipment are not included. Labor time associated with ordering supplies, maintaining devices, training, and regulatory-associated record-keeping are not included. All of these are necessary costs and can vary significantly across facilities. They are also costs that are likely already part of a facility EEP. This example represents only part of the total cost for an enrichment program and is meant **only as a conceptual model** to assist evaluation and comparison of different components and strategies within an overall EEP.

**Note: Calculation for providing videogames is based on the following assumptions: 1) that each apparatus can be used to provide 2 monkeys with simultaneous computer access; 2) that 1hr sessions of computer access are given to each monkey per day (which exceeds to the amount of time monkeys use a foraging device following its delivery). Thus, each system will provide access to 12 monkeys each day and roughly 9 systems would be needed for 100 monkeys. Obviously, the number of systems could be reduced by giving monkeys less frequent access (i.e., fewer days per week). Conversely, more systems would allow for longer sessions and increased per day engagement. Similarly, to provide a reasonable approximation of costs, calculations are based in assuming that each monkey will use approximately 250 pellets in a 1 hour period.