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Simple but Temporally Unpredictable Puzzles are Cognitive Enrichment

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Abstract - Provision of problem solving opportunities as enrichment for animals considered highly intelligent has increased over the last twenty years, but this emphasis on animals considered intelligent may overlook the need for cognitive challenge in species not typified as problem solving animals. Commonly used foraging challenges, such as puzzle feeders, may occupy more of an animal's day with food gathering, but interest in the feeder may wane as animals learn to extract food more efficiently. We tested the hypothesis that making a simple puzzle available at variable intervals can maintain an animal's motivation and be cognitively enriching for species not typically considered "thinking animals." We built and tested a time-delay puzzle feeder with a black rhinoceros (hereafter "rhino") at the San Francisco Zoo. The feeder required the rhino to push a ball to get treats, however food was not always available. An audio cue signaled the availability of food. We assessed the rhino's behavior before and after he learned to use the feeder. The rhino's interest in all enrichment items increased with the feeder, and we found no evidence for habituation to the feeder over time. We also found evidence that the positive behavioral impacts of the puzzle feeder carried over into weeks during which the feeder was not available. Our results highlight the positive impact of providing problem solving opportunities as enrichment for captive animals, and suggest a method for maintaining animal interest in simple puzzle devices by varying reward schedules.

Keywords – Foraging enrichment, Reward schedules, Animal welfare, Anticipatory behavior

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Animal caretakers consider environmental enrichment a best practice (Carlstead & Shepherdson, 2000; Newberry, 1995; Sambrook & Buchanan-Smith, 1997; Shepherdson, 1994; Swaisgood & Shepherdson, 2005). Broadly defined, environmental enrichment aims to stimulate species appropriate behaviors by providing variation in an otherwise static environment (Newberry, 1995; Shepherdson, 1994). Variation can be accomplished by providing dynamic social groups, novel objects, sensory experiences, training, environmental complexity, or problem solving opportunities (Bloomsmith & Lambeth, 1995; Carlstead & Shepherdson, 2000; Franks, Lyn, Klein, & Reiss, 2010; Franks et al., 2013; Langbein, Siebert, & Nürnberg, 2009; Manteuffel, Langbein, & Puppe, 2009a; Sambrook & Buchanan-Smith, 1997). Enriched environments are associated with decreased stress levels, increased positive affect, and a reduction in abnormal behaviors (Bloomsmith & Lambeth, 1995; Carlstead & Shepherdson, 2000; de Azevedo, Cipreste, & Young, 2007; Shyne, 2006; Swaisgood & Shepherdson, 2005). To meet these goals, enrichment "objects" are often deployed in order to provide more variability to an otherwise difficult to modify environment. Nonetheless, maintaining animal motivation to engage with enrichment is challenging (Line, Morgan, & Markowitz, 1991; Meehan & Mench, 2007), as habituation to objects occurs rapidly and stimuli decoupled from a biologically relevant outcome may represent little more than sensory noise (Wells, 2009). Successful enrichments must therefore strike a balance between maintaining animal motivation, providing informative sensory stimuli, and providing opportunities for animals to respond to these stimuli in a species appropriate, goal-directed manner. In other words, enrichment should engage the cognitive processes aimed at assessing and responding to cues from the environment. Providing opportunities to both regularly learn about the environment and apply the outcomes of learning will maintain animals' motivation to engage with their environment (Watters, 2009).

Cognitive enrichment is a subset of environmental enrichment that provides problem solving and learning opportunities to animals. This is different from typical object enrichment where there are no pre-determined conditions of interaction with the enrichment object. Cognitive enrichment works in a multi-step process. First, the animal should receive a reliable cue about an event in its environment. Second, the enrichment should provide the means for the animal to respond to the cue in a species appropriate and goal-directed manner. Finally, the enrichment should provide a positive outcome or reward for gathering and responding to information about the environment (Manteuffel et al., 2009a). Cognitive enrichments thus mimic the innate process of collecting information about an environment and acting on the information to achieve an end goal that is associated with the specific environmental cues. This process is one that all animals have evolved to do in one way or another (Inglis, Forkman, & Lazarus, 1997; Krebs & Watters, 2016; Mench, 1998). Applications of cognitive enrichments in farm and lab settings suggest that providing problem solving opportunities can decrease stress, increase positive affect, improve behavioral resilience and make animals more adaptable to changing environments (Ernst, Puppe, Schön, & Manteuffel, 2005; Imfeld-Mueller & Hillmann, 2012; Langbein et al., 2009; Leotti, Iyengar, & Ochsner, 2010; Manteuffel et al., 2009a; Meehan & Mench, 2007). Providing problem solving opportunities for animals under human care can therefore have major impacts on animal well-being.

Cognitive enrichment is widely used for species characterized as highly intelligent, including great apes (Clark, 2011; Morimura, 2006), elephants (Foerder, Galloway, Barthel, Moore, & Reiss, 2011), or cetaceans (Clark, 2013; Harley, Fellner, & Stamper, 2010). High-tech problem solving enrichments, such as computerized problem solving tasks have proven useful in studying animal cognition in these species (MacDonald & Ritvo, 2016; Morimura, 2006). Nonetheless, species not typified as 'thinking animals' can exhibit complex problem solving methods (Barrett, 2010; Barrett, Henzi, & Rendall, 2007), and may also benefit from opportunities to apply them. A growing body of evidence suggests that animals historically considered cognitively simple are capable of complex cognitive processes (Davis & Burghardt, 2012; Leighty, Grand, Pittman Courte, Maloney, & Bettinger, 2013), and species not typically considered highly intelligent can still benefit from problem solving opportunities (Hagen & Broom, 2004; Langbein et al., 2009). Puzzle feeders are common enrichment objects that require animals to extract food. A lower-tech alternative to computerized tasks, puzzle feeders can be utilized with a variety of species to stimulate problem solving behaviors, although the challenge of balancing difficulty and motivation remains (Ernst et al., 2005; Gottlieb et al., 2011; Novak, Kinsey, Jorgensen, & Hazen, 1998). Simple puzzles may become rapidly 'un-enriching' without a mechanism to vary the challenge, whereas difficult puzzles may result in frustration and disinterest (Meehan & Mench, 2007). Further, traditional puzzle feeders may not impose limits on the reward schedule. Highly motivated individuals may empty a puzzle feeder within a short time of figuring out the puzzle mechanism (Gottlieb et al., 2011; Novak et al., 1998). The result here is that the opportunity to continue to learn or apply learned information is lost. Developing a model for maintaining motivation across a variety of taxa is a critical next step in integrating problem solving opportunities into the broader context of environmental enrichment.

Varying the predictability of receiving a reward can maintain animal motivation across a variety of contexts (Ferster & Skinner, 1957; Watters, 2009; Watters, Miller, & Sullivan, 2011) and may be a useful paradigm to integrate into problem solving enrichments. Motivation to engage in rewarded activities is the highest at intermediate levels of reward predictability in many species (Baldi & Bucherelli, 2005; Chance, 1988), which suggests that varying the predictability of reward for puzzle solving tasks may also maintain animal motivation in this context without the need to develop a puzzle that itself becomes more difficult (Baldi & Bucherelli, 2005; Inglis et al., 1997). Predictability can be changed by altering the probability, timing, or location of the reward (Gilbert-Norton, Leaver, & Shivik, 2009; Kistler, Hegglin, Würbel, & König, 2009; Watters et al., 2011). The opportunity to engage in a task may also be made available to an animal at predictable or unpredictable intervals (Kuczaj et al., 2002; Watters et al., 2011). By integrating unpredictability in the cognitive enrichment paradigm, it may be possible to provide mechanistically simple challenges that remain motivating due to varying reward schedules.

In June of 2015, the San Francisco Zoo and Gardens successfully crowd funded a study to design and build a mechanistically simple puzzle feeding device with unpredictable reward schedules (Dahlhausen, Krebs, Watters, & Ganz, 2016), and assess the behavioral impact of the device on a nine year old male eastern black rhinoceros (*Diceros bicornis michaeli*, hereafter 'rhino'). The enrichment was a heavy duty puzzle feeding enrichment ball, similar in design to a commercially available puzzle feeder for dogs (Christianson, Schechter, & Snyder, 2014). We assessed the behavior of the rhino before and after training to use the puzzle feeder to determine whether introducing the device changed his behavioral patterns. We also assessed the rhino's behavior during periods with and without the enrichment device over a six-week period to see how the presence or absence of the device influenced his behavior.

If the feeder stimulated the rhino's interest in his environment, we expected the rhino to engage more frequently with other enrichment items during weeks with the puzzle feeder than weeks without it. If the enrichment adequately balanced challenge and motivation, we expected that the rhino would interact with the feeder with similar frequency regardless of how many days prior the feeder had been available. As the feeder contained some of the rhino's preferred foods and required active manipulation, we expected that the presence of the feeder would result in the rhino spending more time eating or walking and less time lying down or standing throughout the day compared to data collected before we introduced the feeder or during weeks without the feeder.

Method

Study Subject

The subject of this study was a nine year-old, male black rhino. At the time of the study, the rhino lived in a 1200 m^2 enclosure at the San Francisco Zoo. The rhino involved in this study was the only rhino living in this yard, however the yard abuts another yard where the zoo's other black rhino lives. The substrate of the rhino's yard was soft sand, and the yard contains a number of large rocks and trees. The study subject had no previous experience using puzzle feeders prior to this study.

Puzzle Feeder Mechanism

The puzzle feeding enrichment was designed and built by the design firm who built the original Foobler© puzzle feeder for dogs (Christianson et al., 2014) . The design of the rhino feeder is similar to the dog version, a ball with six internal compartments that hold food. In the original Foobler©, a motor mechanism rotates the internal compartments such that food is dispensed from only one at a time. We built the rhino feeder from a 91.4 cm diameter enrichment ball. The design firm cut into the ball and installed the feeder mechanism, which they built from a standard five gallon (18.9 L) plastic bucket. For the rhino feeder, a rotating lid fit over the compartments to avoid the mechanical effort needed to rotate the internal chambers. There was approximately 30 cm of space between the top of the food compartments and the top of the ball. We built a lid for the feeder from the top part of the ball, which we cut off, inverted, and bolted into place after installing the feeder mechanism. The assembled feeder resembled a regular enrichment ball with an indentation (41 cm diameter), and an off-centered hole in the indentation to dispense food. An audio tone signaled when a food compartment became available. To get the food out when a compartment opened, the rhino had to roll the ball and knock the food out of the inner compartment and through the hole in the lid of the ball. The food compartments and the hole in the top of the ball did not always line up, as such, not every push of the ball resulted in a food reward. We used apples, sweet corn, commercially available horse treats, and occasionally other food items in the feeder. The feeder dispensing mechanism is Bluetooth enabled. Using a Bluetooth device and app, we could either set the times the food compartments would open or use the Bluetooth connection to open the next food compartment remotely. The audio tone could also be played using the Bluetooth app without opening another food compartment.

Training

Training the rhino to use the feeder required training him to push a ball to obtain a food reward, and associate an audio tone with the availability of food. To train the rhino to push a ball for food, we removed the inner feeding mechanism and used the outer shell of the feeder to train several intermediate behaviors. We continued training each intermediate behavior until the rhino showed no hesitation in performing the goal behavior for that phase. In practice, each phase lasted about a week. As the rhino typically received his morning feed in a large rubber bowl, we began training by placing the ball on top of his bowl so he would have to push the feeder shell to get to his regular diet. We then took away the bowl and placed the ball, top side down, on top of a small amount of food. Once the rhino adjusted to this, we started placing 5 – 10 pieces of high-value foods inside the ball so the rhino had to push the ball over to get the food out. As the hole in the lid of the feeder was positioned down, the rhino frequently received a reward for the first push although some food may have remained in the feeder. During all phases without the bowl present, the rhino had access to his regular diet outside of the feeder. For the final training phase, we placed the shell of the feeder with the lid facing up and food inside the ball, forcing the rhino to push the ball all the way over at least once to get the high value food.

We trained the rhino to associate the audio tone with the availability of high value foods through classical conditioning. We played the tone, then fed the rhino a high value food item, and repeated this between 5 – 10 times per session. We conducted conditioning sessions during the same time period we were training the rhino to push the ball; however, conditioning sessions generally happened in the afternoon while other training took place in the morning.

Once the rhino regularly pushed the ball to get food out without the internal dispensing mechanism, we re-assembled the feeder and loaded the compartments with food. To make sure the rhino understood how the feeder worked, we used the Bluetooth control feature of the feeder to remotely control the availability of food from the front of the exhibit. As the rhino approached within 2 m of the ball, we either played the audio tone if a food compartment was available, or opened the next compartment. Once we verified that the rhino responded to the audio cue by approaching the ball and pushing it over to get food at least twice on three consecutive days, we considered the rhino fully trained on how to operate the feeder.

Study Phases

To establish an understanding of the rhino’s behavioral patterns before the introduction of the feeder, we collected baseline behavioral data from June of 2015 – March of 2016. From March of 2016 through May of 2016, we trained the rhino how to use the feeder. In June of 2016, we conducted a six-week experiment to assess how the rhino’s behavior changed in response to the presence or absence of the feeder.

Baseline Data Collection

We developed and tested the ethogram used for data collection in May of 2015 (Table 1), and baseline data collection began in June of 2015. A single observer collected all baseline data during hours the zoo was open to the public, between 10 AM and 5 PM. We collected data opportunistically throughout the baseline period; however, on days when data were collected, the observer conducted at least two 20-minute observation sessions. We used one-minute instantaneous scan sampling to collect data on the rhino's behavior. From baseline data, we identified the rhino's daily temporal pattern. The rhino was typically active after the morning servicing of his yard, laid down or was minimally active during the middle of the day, and became active again in the afternoon.

Table 1

Ethogram Used for Interval Behavioral Observations

Behavior	**Definition**
Urine Spray	Rhino sprays urine on an object.
Stand	Rhino stands on all four feet. No other behavior is occurring.
Lie Down	Rhino is lying down. Eyes can be open or closed.
Walk	Rhino moves from one place to another via walking.
Eat	Rhino consumes food. Includes grasping, reaching for or pulling on browse with mouth, chewing, or otherwise processing food items.
Run	Rhino moves from one place to another via running. This includes any locomotion where two or more feet are off of the ground at the same time.
Sniff	Rhino waves upper lip in the air. Similar to the flehmen response. Must not occur in the process of reaching for or attempting to consume food.
Mouths	Rhino licks object or substrate. Object or substrate cannot be a food item.
Drink	Rhino drinks water.
Startle	Rhino changes direction rapidly, jumps back, retreats, or runs away from an object, sound, or other stimulus.
Scratch	Rhino rubs body part against an object.
Push/Pull	Rhino pushes or pulls object with mouth or horn.
Chase peafowl	Rhino runs or trots towards a peafowl*.
Keeper Interaction	Rhino interacts with keeper, either during a training session or a keeper talk.
Out of Sight	Rhino is not visible.

Note. San Francisco Zoo is home to free-range peafowl, some of whom live in and around the black rhino exhibit.

Experimental Data Collection

After training the rhino to use the feeder, we conducted a six-week study of the rhino's behavior with and without the feeder beginning in June of 2016. During the experiment, we collected at least two twenty-minute data sessions during the morning (9:00 AM – 11:30 AM) and afternoon (2:30 PM – 5:00 PM) time periods. We collected but did not analyze data from the mid-day time period, as the feeder did not open new compartments between 11:30 AM and 2:30 PM. We deployed the puzzle feeder Monday through Friday, then removed the feeder for a week, and repeated this pattern over a six-week period. We collected data at least three days a week during the experiment. During weeks with the feeder deployed, we assigned three random times for food dispenses in the morning and afternoon periods using the Bluetooth app. We did not dispense food in the mid-day period because the rhino spent most of this time asleep, and the likelihood of him noticing the audio cue was low.

We recorded interactions with enrichment items only on the one-minute data collection intervals during baseline observations ("Push/Pull," Table 1). As we observed only two interactions with enrichment occurring on the minute during baseline observations, we added an all occurrence "interact with enrichment" behavior for data collection during the experimental study. We defined the all occurrence behavior "interact with enrichment" as the rhino approaching an object and touching it with his nose, horn, or mouth, including pushing, pulling, or sniffing an object if the rhino contacted the object while sniffing it. If the rhino incidentally made contact with an enrichment item with a body part other than his nose, horn, or mouth, such as brushing past an item while walking through the exhibit, we did not count this as an item interaction.

The observer who collected the baseline data trained two additional observers on data collection for the experiment. We ensured inter-rater reliabilities by having two observers record data at the same time, then calculating Fleiss' kappa (Fleiss, 1971) from the simultaneously collected data. If reliabilities were less than 0.8, we did not use the session in analysis, and the observers recorded data together until they met or exceeded the desired reliability level.

The husbandry, diet, and enrichment regimes of the rhino did not change between feeder and non-feeder weeks besides the availability of the puzzle feeder. The feeder did not provide a significant portion of the rhino's diet, and the rhino had access to his daily diet in the form of hay, browse, and other produce at all times during the study. The rhino also had enrichment besides the feeder available throughout the study, including item enrichments and food spread throughout his enclosure. To ensure that the addition of the feeder did not add to the workload of animal care staff and unintentionally decrease deployment of other enrichment items during the study, researchers set up the feeder during the weeks that it was deployed. Although which enrichments were available may have differed from day to day, the amount of non-feeder enrichment was similar across weeks with or without the feeder.

Statistical Analyses

We excluded any interval behavior occurring in less than 1% of the total observations from further analyses due to small sample size. For instance, scratching occurred 14 times out of roughly 2,940 min of total interval observations, and was excluded from further analysis. Of the fourteen interval behaviors listed in the ethogram, five occurred in more than 1% of the total observations and were analyzed further: eating, lying down, sniffing, standing, and walking. We collected 8 hrs (26 observation sessions) of baseline data. After training the rhino to use the feeder, we collected 14 hrs (42 observation sessions) of observations during weeks the feeder was deployed and 26 hrs (79 observation sessions) during weeks without the feeder.

To assess whether the rhino's motivation to engage with the feeder changed during the study, we compared the per observation session number of interactions with the feeder during the first and last days of each week with the feeder present. We used Fisher's exact test to compare the per observation sessions number of interactions during the first day the feeder was deployed to the last day the feeder was deployed during a given week. We also assessed whether all occurrence interactions with enrichment items, including the feeder, occurred more frequently during feeder weeks than non-feeder weeks using a one-tailed Welch's t-test.

We used a two-way multivariate analysis of variance (MANOVA) to assess changes in the rhino's behavior at the observation session level. The total occurrences of the five behaviors during an observation session comprised the vector of dependent variables, with the experimental treatment (baseline, feeder or no feeder) and time period (early or late) included as the independent variables. We included an interaction term between treatment and time period because we expected time of day could influence the rhino's response to the feeder. If the interaction term was found to be non-significant, we removed the interaction and re-ran the model. We compared all experimental treatments to assess whether the rhino's behavior differed among treatments (Table 2). Once we established that there were differences in behavior among treatments, we used the same two-way MANOVA model to compare baseline behavior to behavior during weeks with the feeder, as well as behavior during weeks with the feeder to weeks without the feeder. We used a Bonferroni correction to account for multiple comparisons. If treatment had a significant effect in the MANOVA model, we ran Bonferroni corrected univariate two-way analysis of variance (ANOVA) tests on eating, lying down, standing, and walking with treatment and time period as independent variables to assess how these behaviors changed in response to treatment.

Results

We observed the rhino interacting with all enrichment items 73 times during weeks with the puzzle feeder (42 observation sessions), and 36 times during non-feeder weeks (79 observation sessions). Of the all occurrence interactions with enrichment items during weeks with the feeder, 75% (55 interactions) were with the feeder. We did not collect data on all occurrence interactions with enrichment items during the baseline observations; however we observed the rhino interacting with enrichment items twice on data collection intervals during baseline data collection (2 of 520 observations, 0.3% of total observations). By comparison, the rhino interacted with enrichment items excluding the feeder 32 times on data collection intervals during the study (32 of 2,420 observations, 1.3% of total observations, including weeks with and without the feeder). If the rhino's rate of interaction with enrichment items was similar during baseline observations as during the experimental study, we would have expected to observe between 6 and 7 interactions with enrichment items occurring on the one minute data collection intervals (Expected Baseline Interaction Rate = (32/2,420)*520). During feeder weeks, the rhino interacted with enrichment objects including the feeder 1.3 times per observation session (SD = 3.95), whereas during weeks without it he averaged 0.33 interactions per observation session (SD = 1.33), $t(70) = 2.21$, $p = 0.03$, 95% CI [0.09, 1.82] (Figure 1), however when interactions with the feeder were not included, the average number of interactions did not differ between feeder (M = 0.28, SD = 0.72) and non-feeder weeks (M = 0.37, SD = 1.4), $t(207) = -0.61$, $p = 0.54$, 95% CI [-0.36, 0.19], Figure 2). The rhino interacted with the feeder a similar number of times per day during the first day of feeder weeks (M = 4.0, SD = 2.6) compared to the last day the feeder was available that week (M = 4.66, SD = 4.7; Fisher's exact test, $p = 0.13$).

Table 2

Multivariate Analysis of Variance (MANOVA) Results of the Rhino's Behavioral Response to All Three Experimental Treatments (Baseline, With Feeder, Without Feeder)

	All Treatments				
Variable	**DF_1**	**DF_2**	**Pillai's Trace**	**$F^{\dagger}$**	***p*-value**
Treatment	10	368	0.18	3.66	< 0.001 *
Time Period	5	183	0.22	10.4	< 0.001 *

Note. A non-significant interaction term between treatment and time period was dropped from the model, $F(10, 368) = 1.50$, Pillai's trace = 0.07, $p = 0.13$.

† F values are approximated when using Pillai's trace.

* $p < 0.05$.

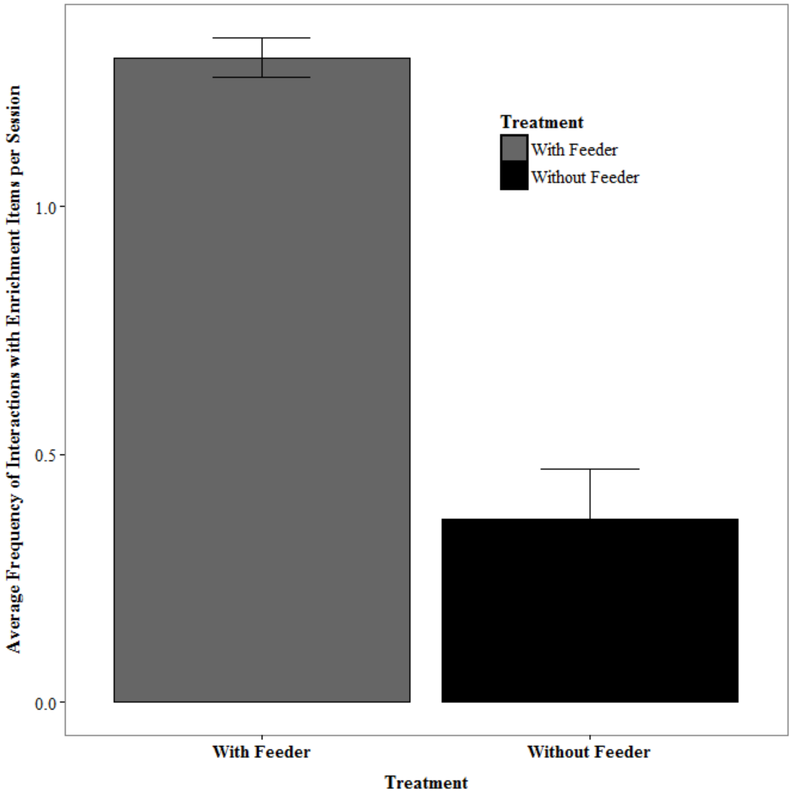

Figure 1. Average number of times the rhino interacted with any enrichment, including the feeder, per observation session for weeks with and weeks without the feeder. Error bars represent ± one standard error.

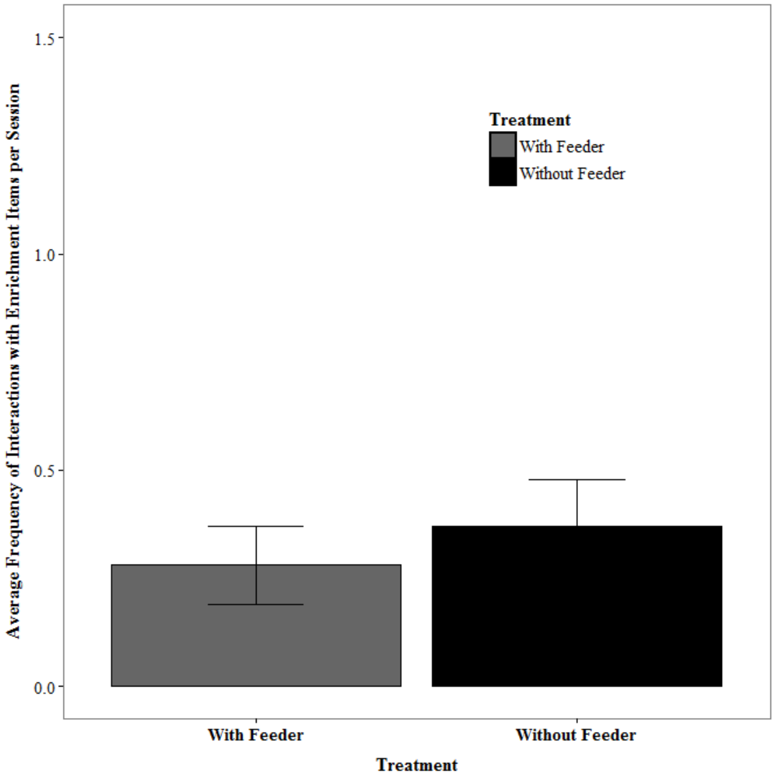

Figure 2. Average number of times the rhino interacted with enrichment items, excluding the feeder, per observation session for weeks with and weeks without the feeder. Error bars represent ± one standard error.

We found a significant impact of treatment and time period on the rhino's behavior across all treatments (baseline, with feeder, without feeder; *p* < 0.001, Table 3), and there was no interaction among treatments and time periods. The rhino's behavior during weeks with the feeder differed significantly from his baseline behavior (*p* < 0.001, Tables 3 – 4). The rhino spent more time eating and less time standing during weeks with the feeder compared to his baseline behavior (*p* = 0.04 and *p* < 0.001 respectively, Table 4). The rhino's behavior differed between feeder and non-feeder weeks (Table 5, Figures 3 – 4), however there were no differences in the frequency of eating, walking, standing or lying down between weeks with and without the feeder.

Table 3

MANOVA Results Comparing Baseline Behavior to Behavior during Weeks with the Feeder

	Baseline Behavior to Feeder Weeks				
Variable	**DF_1**	**DF_2**	**Pillai's Trace**	**$F^{\dagger}$**	***p*-value**
Treatment	5	61	0.31	5.56	< 0.001 *
Time Period	5	61	0.34	6.32	< 0.001 *

Note. A non-significant interaction term between treatment and time period was dropped from the model, *F*(5, 60) = 0.64, Pillai's trace = 0.12, *p* = 0.16. All *p*-values Bonferroni corrected for multiple comparisons.
† *F* values are approximated when using Pillai's trace.
* *p* < 0.05.

Table 4

Two-Way ANOVA Results Comparing Baseline Behavior to Behavior during Weeks with the Feeder

	Baseline to Feeder Weeks					
	Variable	**DF_1**	**DF_2**	***F***	***p*-value**	**Corrected† *p*-value**
Eating	Treatment	1	65	5.30	0.02 *	0.04 *
	Time Period	1	65	29.4	< 0.001 *	< 0.001 *
Lying Down	Treatment	1	65	2.63	0.1	0.2
	Time Period	1	65	4.7	0.03	0.06
Sniffing	Treatment	1	65	3.68	0.05	0.1
	Time Period	1	65	0.20	0.64	1
Standing	Treatment	1	65	15.00	< 0.001 *	< 0.001 *
	Time Period	1	65	1.33	0.25	0.5
Walking	Treatment	1	65	0.20	0.65	1
	Time Period	1	65	1.61	0.20	0.40

†Corrected using Bonferroni correction.
* *p* < 0.05.

Table 5

MANOVA Results Comparing Behavior during Weeks with the Feeder to Behavior during Weeks without the Feeder

	Feeder to Non-Feeder Weeks				
Variable	**DF$_1$**	**DF$_2$**	**Pillai's Trace**	***F***	***p*-value**
Treatment	5	160	0.07	2.66	0.04 *
Time Period	5	160	0.22	9.04	< 0.001 *

Note. A non-significant interaction term between treatment and time period was dropped from the model ($F_{5,159} = 1.38$, Pillai's trace = 0.04, $p = 0.23$). All p-values Bonferroni corrected.
† *F* values are approximated when using Pillai's trace.
* $p < 0.05$.

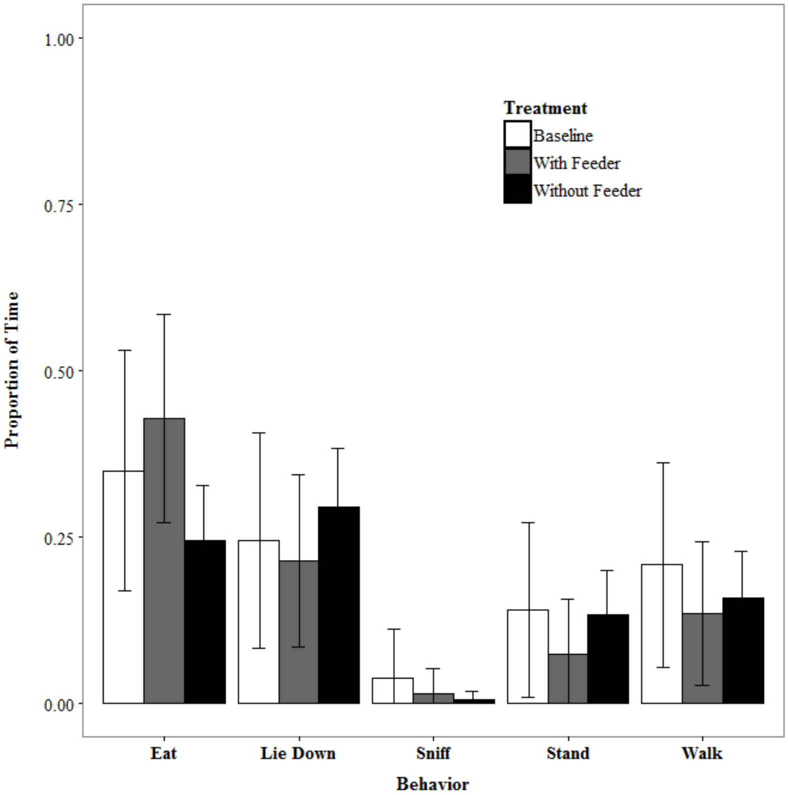

Figure 3. Time budget of the rhino between 9:00 AM – 11:30 AM by behavior and treatment. Error bars represent ± one standard error.

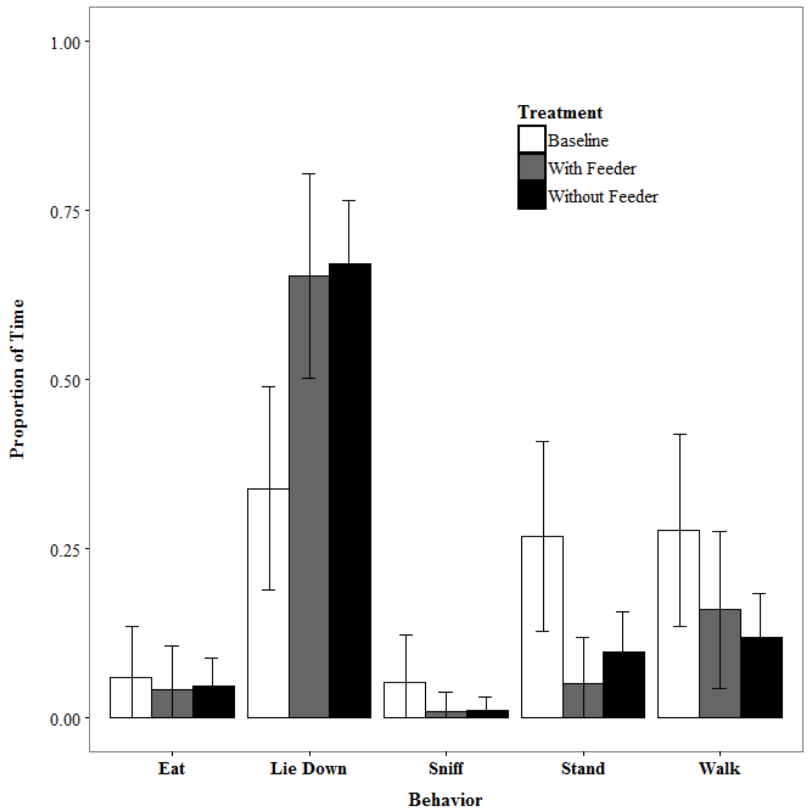

Figure 4. Time budget of the rhino between 2:30 PM – 5 PM by behavior and treatment. Error bars represent ± one standard error.

Discussion

The rhino showed a preference for the puzzle feeder over other forms of enrichment (Figure 1). He interacted with it at similar frequencies during the first and last days it was deployed despite the simple dispensing mechanism. Our findings are consistent with other applications of cognitive enrichments in farm animals, with animals maintaining their interest in performing a task to obtain a reward over time (Boissy & Lee, 2014; Ernst et al., 2005; Puppe, Ernst, Schon, & Manteuffel, 2007; Zebunke, Puppe, & Langbein, 2013). Thus, the puzzle feeder used in this study appears to have balanced challenge and motivation for the rhino by integrating temporal unpredictability into a simple puzzle feeding device. Our findings support the benefits of providing problem solving opportunities for animals across taxa, even those not considered 'problem solving' species.

We observed an increase in time spent eating when comparing baseline data to weeks with the feeder (Table 4, Figures 3 and 4), which was consistent with our predictions. We observed a decrease in standing behavior during weeks with the feeder compared to baseline data, which was also consistent with our predictions. The rhino stood less frequently during weeks with the feeder than compared to his baseline behavior, and this change was more pronounced in the afternoon time period (Figure 4). In this same time period, we observed a decrease in walking during the experiment, although the decline was not statistically significant (Figures 3 and 4). In baseline observations, the rhino spent about 30% of his time walking near the back gate of his exhibit during afternoon observations. The path he walked varied, but generally took approximately one minute to complete, and he usually stopped and stood for a moment at the end, accounting for the corresponding 30% of his time spent standing (Figure 4). When the zoo closes, the rhino gets let into his barn through the back gate and receives his evening meal. In other species, anticipation of scheduled feedings manifests as increased activity prior to the known feeding time (Anderson, Yngvesson, Boissy, Uvnas-Moberg, & Lidfors, 2015; Dantas-Ferreira et al., 2015; Davidson, Tataroglu, & Menaker, 2005; Folkedal et al., 2012). Increased activity levels prior to feeding may also be accompanied by an increase in ‘searching’ behaviors, such as looking or sniffing, and a spatial focus of activity near the location of the expected feeding (Baerends, 1976; Hinde, 1953; Innis, Simmelhag-Grant, & Staddon, 1983; Krebs, Torres, Moon, Chesney, & Watters, in press; Silva & Timberlake, 2005). The rhino’s behavior late in the day thus seems consistent with appetitive behavioral patterns preceding a scheduled feeding. The introduction of the puzzle feeder altered this suite of behaviors, resulting in less overall activity preceding the evening feeding. Providing numerous, small positive opportunities throughout an animals’ day has been theorized to reduce the intensity of anticipatory behaviors exhibited in response to a predictable reward (Watters, 2014). The change in the rhino’s behavior between baseline and experimental observations supports the modulation of his anticipatory behavior by providing opportunities for him to engage in problem solving for small rewards throughout the day.

Current environmental enrichment practices emphasize providing animals under human care with choices and control in their environments (Bassett & Buchanan-Smith, 2007). In this study, the puzzle feeder accomplished both goals. Similar to other item enrichments, the presence of the feeder provided the rhino with the choice of whether to interact with it. Unlike typical novel objects, however, the puzzle feeder provided a cue periodically reminding the rhino of its presence and the opportunity to obtain a reward. The rhino could then choose to respond to the cue or not multiple times throughout the day. In this sense, the puzzle feeder provided more opportunities for the rhino to exert agency regardless of whether he was interested in interacting with the feeder. Lab studies of pigeons, rodents, and humans, indicate having more options is preferred to fewer even if alternative opportunities do not change the qualitative outcome of an animal’s choice (Leotti et al., 2010). This suggests the opportunity to make a choice in itself may be a positive experience (Leotti et al., 2010; Owen, Swaisgood, Czekala, & Lindburg, 2005; Perlmuter & Monty, 1977). Thus, even when the rhino was not interested in interacting with the feeder, the opportunity to decide not to do so was likely a positive event. It is possible that with respect to the third component of the definition of cognitive enrichment – that the enrichment should provide a positive outcome or reward for gathering and responding to information about the environment – not responding to a cued opportunity also supports positive psychological outcomes for animals. Furthermore, the preference for more choices is tightly linked to the perception of control, in humans and in other species (Ernst et al., 2005; Franks & Higgins, 2012; Perlmuter & Monty, 1977; Sambrook & Buchanan-Smith, 1997). Beyond giving a choice to interact with the feeder, the rhino feeder also gave the rhino a degree of control in obtaining preferred food items throughout the day, rather than requiring him to wait for a training session or meal. The puzzle feeder was thus successful at meeting the goals of cognitive enrichment (signal an opportunity, require action by the animal to achieve opportunity, positive outcome or reward for engaging in or perhaps even refusing to engage in the opportunity, (Manteuffel et al., 2009a; Manteuffel, Langbein, & Puppe, 2009b), while simultaneously providing elements of choice and control into the rhino’s day-to-day life.

We did not observe a decline in the average number of times the rhino interacted with the feeder during the first and last days of a feeder week, however, this does not mean habituation did not occur. The exposure time to the feeder was relatively short in this study and the one week with, one week without the feeder study design could have delayed the rhino’s habituation to the feeder (Kuczaj et al., 2002). Future research should further examine the impact of temporal unpredictability of an enrichment’s availability on the rate of habituation to a novel item.

Besides all occurrence counts of interactions with enrichment items, the rhino’s behavior did not change significantly between feeder and non-feeder weeks. Several factors may account for the absence of observed differences in his behavior between feeder and control weeks. The length of time of each treatment was perhaps not long enough to observe subtle differences develop in the rhino’s behavior, particularly in the context of the five most frequent behaviors. Providing the puzzle feeder may also have stimulated changes in the rhino’s behavior that became persistent in the absence of the feeder. Challenging animals with cognitive enrichments has been found to increase their self-perception of effectiveness within their environment (Meehan & Mench, 2007). Changing an animal’s perception of their ability to affect change or have control in their environment may have lasting positive impacts on the animal's behavior and well-being. The 36 interactions with enrichments during non-feeder weeks suggest the rhino had an increased interest in the environment even in the absence of the feeder compared to the baseline data. A similar response to puzzle feeders has been observed in laboratory housed macaques, with foraging behaviors increasing in the time periods after a puzzle feeding device was removed from the enclosure (Gottlieb et al., 2011). Cognitive enrichment opportunities may therefore have a lasting positive impact on animal behavior, even in the absence of the enrichment device.

Besides the training related to the puzzle feeder and the deployment of the puzzle feeder, there were no other changes to the rhino's enrichment or husbandry regimes in this time frame that would account for the observed changes in his behavior. Thus our study supports the utility of combining unpredictability with problem solving opportunities to maintain animal motivation to engage with problem solving enrichments. It also suggests that cognitive enrichment has carry-over effects that promote animals' interest in their environment and supports their perception of their own effectiveness (Franks & Higgins, 2012). Future work should expand on these concepts and determine their generalizability across species and environmental contexts.

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