Short title: Foraging enrichment and cockatoo behavior

Foraging enrichment alleviates oral repetitive behaviors in captive red-tailed black cockatoos (*Calyptorhynchus banksii*)

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Abstract

The relationship between inadequate foraging opportunities and the expression of oral repetitive behaviors has been well documented in many production animal species. However, this relationship has been less-well examined in zoo-housed animals, particularly avian species. The expression of oral repetitive behavior may embody a frustrated foraging response, and may therefore be alleviated with the provision of foraging enrichment. In this study we examined the effect of different foraging-based enrichment items on a group of captive red-tailed black cockatoos who were previously observed performing oral repetitive behavior. A group of six cockatoos were presented with five foraging enrichment conditions (no enrichment (control), sliced cucumber, fresh grass, baffle cages and millet discs). Baseline activity budgets were established over a 10-day pre-intervention period and interventions were then presented systematically over a 25-day experimental period. This study demonstrated that the provision of foraging interventions effectively increased the median percentage of time spent foraging compared to control conditions (range 5.0 – 31.7 % across interventions vs 5.0 % for control), with two of the interventions; grass and millet discs, significantly decreasing the expression of oral repetitive behaviors (control = 16.6 vs 8.3 % for both grass and millet discs) . Finally, a rapid-scoring method utilized by zookeepers during the study proved to be a useful proxy for the amount of time the cockatoos spent interacting with the foraging interventions and overall time spent foraging.

Key words

Environmental enrichment, Oral repetitive behavior, Stereotypic behavior, Captive environment, Parrot

Introduction

Zoos are increasingly playing an important role in wildlife conservation; through education, interactive experiences, and captive breeding programs (Tribe, 2003; Webber et al., 2016). However, the nature of the captive environment means that some of the survival strategies employed by animals in the wild, such as foraging for food, can be constrained by captive conditions; often requiring less time and energy expenditure to fulfil. As a result, the maintenance of species-typical behavioral profiles and the provision of naturalistic foraging opportunities is a key challenge faced by zoos today.

Stereotypies (or other abnormal repetitive behaviours) are defined as repetitive, invariant behaviors with no apparent goal in the context in which they are being performed (Dantzer, 1991; Garner, 2008; Mason, 1993), and are not known to occur in the wild (Mason et al., 2008). This contrasts with the complex, variable and diverse characteristics of adaptive, functional behavior (Lewis et al., 2006). The development of stereotypies has been correlated with a restricted capacity to fulfil a specific behavioral need (Appleby & Lawrence, 1987; Mason & Rushen, 2008). In many animal species, inadequate foraging opportunities and the subsequent inability to carry out naturalistic foraging behaviors results in the expression of abnormal oral behaviors. For example, licking of non-food objects in giraffe may be significantly reduced by increasing the complexity of foraging devices to facilitate tongue manipulation (Fernandez et al., 2008). In avian species, feather damaging behavior (e.g. feather picking or chewing) is a detrimental form of abnormal repetitive behavior, whereby self-harm is inflicted by excessive and dysfunctional preening behavior (for a review, see van Zeeland et al., 2009). Feather damaging behavior can be alleviated however, as has been shown in the Crimson-bellied conure, where excessive feather picking decreased as a result of the provision of natural and edible materials such as fruit baskets and willow branches (van Hoek & King, 1997). Similarly, in Amazon parrots, feather picking was significantly reduced with the provision of foraging-based enrichment (for example, fruit cages), which was preferred over other non-foraging physical enrichments (for example, plastic toys) (Meehan et al., 2003). These studies therefore not only suggest that abnormal oral behaviors may be consequential to inadequate foraging opportunities, but that the provision of effective foraging interventions can alleviate these behaviors.

Positive effects associated with providing foraging enrichment in zoos have been shown to improve the welfare of captive avian species (Field & Thomas, 2000; Meehan & Mench, 2006), with many studies further investigating their contribution towards reduced abnormal behavior (e.g. Amazon parrots, Meehan et al., 2004; Grey parrots, Lumeij & Hommers, 2008; Budgerigars, Polverino et al., 2015). Specifically, foraging enrichment aims to encourage behaviors involved in food acquisition (i.e. hunting and scavenging) and consumption. However, compared to primates and carnivores, little is known about what constitutes an effective foraging enrichment strategy in captive avian species, in particular, there is little useful empirical data for cockatoo species (King, 1993; and for a recent review, see Rodríguez-López, 2016). Furthermore, most studies investigating the efficacy of foraging enrichment on captive avian species are performed on individually housed subjects (Meehan et al., 2003; van Zeeland et al., 2013; Rozeck et al., 2010) or pairs (van Hoek & King, 1997). One study on the effect of foraging enrichment on a group of captive macaws observed marked behavioral changes (Reimer et al., 2016), but not in relation to improving foraging times or mediating abnormal behaviors. Thus, the efficacy of foraging enrichment strategies for group-housed birds in zoos requires further scrutiny.

Group-housing is a common occurrence in zoos. Birds that are trained to fly in free-flight bird shows for educational and entertainment purposes are often housed in simple aviary environments and are maintained on a restricted diet. These birds are therefore especially dependent on the provision of environmental enrichment to facilitate the expression of normal behaviors in the absence of a naturalistic environment, which might otherwise provide opportunities to forage and contribute to wild-type activity budgets (Fàbregas et al., 2012). Moreover, enrichment can help to provide mental stimulation for species with complex cognitive abilities such as Parrots (Emery & Clayton, 2004; Emery, 2006), which have the ability to seek out stimulating activities to fulfil their own enjoyment (Emery & Clayton, 2015). As such, the provision of a varied and complex foraging enrichment plan will contribute to an improved welfare state of group-housed gregarious species such as psittacines.

At Taronga Zoo, captive red-tailed black cockatoos (*Calyptorhynchus banksii*; hereafter RTBC) trained to fly in the daily free flight bird shows are maintained on a restricted diet. The ease at which their food is accessed and consumed means that the RTBC spend little time searching, extracting and processing their feed; activities which significantly contribute to overall foraging duration (van

Zeeland et al., 2013). As a result, they can spend as little as twenty minutes per day consuming their allocated diet. This is in contrast to wild cockatoos that typically forage in the early morning and late afternoon, spending anywhere from 13-44 % of the day finding and processing food (Chapman & Paton, 2005; Stock et al., 2013; Styche, 2000). The lack of foraging opportunities may have contributed to the development of oral stereotypies in this species (M. Fangmeier pers. obs.), therefore given their natural food sources (seeds, nuts, fruits and berries from native trees; Mulawka, 2014) and foraging patterns, we hypothesized that by providing more naturalistic foraging-based enrichment to increase the amount of time birds spent extracting and processing food, we would see a decrease in oral stereotypic behavior. We therefore aimed to, (1) identify the daily activity budget for a group of captive RTBC trained to fly in a free-flight bird show to determine time spent performing foraging and oral repetitive behavior under normal (baseline) conditions; (2) determine the effect of providing a range of foraging interventions on the determined activity budget; and (3) to develop a rapid-scoring method to assess the efficacy of the foraging interventions.

Methods

Subjects, housing and husbandry

Subjects were male (n = 3) and female (n = 3) RTBC aged 4 to 9 years. All subjects were housed at Taronga Zoo, Sydney, Australia, in an off-exhibit area behind a free-flight bird show arena. The youngest, a female, had an unknown rearing history as she was acquired through the Taronga Zoo Wildlife Hospital as a juvenile. The remaining five RTBC were hand reared and acquired through a local breeder. Housing consisted of two more or less identical covered aviaries (5 x 2 x 3m, depth x length x height) side by side, with two small openings allowing free movement between them. The walls and ceilings of the aviaries were constructed from stainless-steel mesh, with concrete flooring and a tin roof covering a third of the enclosure. Branches were provided for perching and chewing. Various types of fresh browse (Eucalyptus, Banksia, Casuarina and Callistemon depending on availability) were attached to the aviary walls, and were replaced every Friday afternoon at 16:00. Aviaries were situated along a single corridor in close proximity to other parrot species flown in the free-light bird show. The RTBC had visual access to adjacent aviaries and the corridor.

When weather conditions permitted, five of the six RTBC flew in the free-flight bird show twice daily at 12:00 and 15:00, while the youngest remained in the aviary to feed. The RTBC were loaded into individual mobile cages at approximately 11:30 and 14:30, and returned to their aviaries at 12:30 and 15:30 respectively following the free-flight bird show. During the shows, the RTBC were flown briefly (<1 minute), and then returned to the off-exhibit area to be fed their daily feed rations in the same individual mobile cages to monitor individual food intake (for husbandry purposes). If the bird show was cancelled due to poor weather, such as heavy rain or strong winds, all six RTBC were instead loaded into the individual cages to be fed at 11:30 and 14:30. Their feed consisted of equal portions of multi-vitamin pellets and a soaked seed mixture, with an additional single fruit or vegetable item (apple, paw-paw, corn, grapes, pear, peas or sweet potato rotated throughout the week). They received 50 % of their daily feed intake after the first show, and the remaining 50 % after the second show.

Prior to this study, all birds trained to fly in the free-flight bird show, including the RTBC, were given low calorie forage (sliced cucumber, kale or cauliflower) following feeding. At least once weekly, this low-calorie forage was substituted with a random foraging intervention (including but not limited to grass, millet discs, vegetable skewers, vegetables in cardboard tubes, shredded paper and leaf litter). So as to facilitate the current study, this forage was not provided during the study period (including baseline conditions).

The keepers interacted with the RTBC a minimum of six times a day during general husbandry activities, with keeper interaction per bird lasting 1-5 minutes. Aviaries were cleaned daily between 8:00 and 10:00.

Behavioral observations and foraging interventions

Data was collected during November and December 2015 over 35 days, with observations occurring Monday-Friday. Observations consisted of two weeks collecting baseline data (10 days), where the

RTBC did not receive any additional foraging intervention, followed by five weeks of data collection where foraging interventions were introduced. The days that each foraging condition was presented were randomized such that they were only presented once per week, and were presented on a different day each week.

The birds were presented with five foraging conditions Foraging conditions included; (1) no enrichment (control), (2) cucumber slices; twelve slices of cucumber (~1.5 cm width) spread on the floor of the aviaries (six slices per aviary), (3) grass; four large clumps of long grass (grown in pots) with the soil and roots spread on the floor of the aviaries (one pot divided into two clumps per aviary), (4) baffle cages; four stainless steel baffle cages containing two whole kale leaves and one Banksia cone hung on the walls of the aviaries (two baffle cages per aviary), and (5) millet discs; six small pancakes (~6 cm diameter) made up of a mixture of flour, water and millet seed hung on the walls of the aviaries near branches using twine (three discs per aviary) (Figure 1). All interventions were spread evenly over the provided area and the position of the foraging interventions varied between provisions. On days where data was not collected, the RTBC did not receive any additional foraging intervention.

Instantaneous scan sampling (Martin & Bateson, 2007) at 10-minute intervals from 8:10 to 11:30, 12:30 to 14:30, and 15:30 to 15:50 was used to record broad state behaviors for each individual. One-zero time sampling (Martin & Bateson, 2007) at 1-minute intervals was used to record individual interactions with foraging interventions, and summed as a proxy for duration of interaction. Descriptions of recorded behaviors are listed in the ethogram (Table 1). Foraging interventions were presented twice a day at 10:00 and 13:00 for 90-minutes. All data were collected by one researcher (M. Fangmeier) who sat opposite the RTBC aviaries in a narrow corridor approximately 2m in width.

Rapid assessment method

At 11:30 and 14:30, once the RTBC had been removed from their aviaries, the keepers were asked to visually assess the overall use of the foraging interventions, scoring the intervention usage (grass) or consumption (millet discs, cucumber and baffle cages) on a scale of 1-5 (Table 2). For consistency, the same two keepers were involved in this assessment. Where both keepers were present, they would give one score collaboratively. This ensured that, where one keeper was absent, the score that was given in the absence of that keeper was an accurate representation of previous observations. Scores were given in the absence of, and without prior discussion with, the observer. These scores were collected by the observer once all other data had been collected for the study.

Statistical analysis

To investigate whether foraging condition significantly affected either the time spent foraging or the time spent performing oral repetitive behaviors, as a proportion of the total observation period, binomial mixed effects models were constructed; with the proportion of time spent performing the behavior as the dependent variable, forage condition as the independent variable, and individual identity as a random factor. These models were compared to the null model for both behaviors. Some observation times were under-represented in this sample due to the birds being removed from their aviaries for the show early, or returned late. The data was therefore subsetted such that times when more than four observations (across all birds, across the 20-day experimental period) were missing were excluded from the dataset. This resulted in 30 observations per day, including a minimum of 5 birds per observation period.

To test whether the keeper usage scores (KS) in the rapid-scoring method were related to the proportion of time that the RTBC had spent interacting with the intervention, the overall time spent foraging, or the overall time spent performing oral repetitive behaviors, Poisson generalized linear models were constructed; with the KS as the response variable, and proportion of time spent performing the behavior and enrichment type as explanatory variables. As KS was necessarily a single value for each provision of enrichment, the RTBC behavior was also pooled for the period that the enrichment was provisioned, i.e. the mean proportion of the 90-minute period spent performing a behavior was calculated, across all birds.

All analyses were performed in the R environment for statistical computing (R core team, 2015).

Results

Baseline activity

Baseline activity budgets revealed that the RTBC spent most of their morning (8:10-11:30) resting or performing maintenance behaviors. Resting behaviors were highest in the early mornings, declining towards 12:00, while maintenance behaviors increased across the morning proportionate to the decline in time spent resting (Figure 2a). After the 12:00 bird show/feed, the RTBC would consistently perform high levels of oral repetitive behaviors (median across birds of 35.0 % - 62.5 %; Figure 2b); including both self-directed and metal-directed behaviors. In some individuals, this behavior would continue until they were removed from their aviaries at 14:30, and would often continue following the 15:00 bird show/feed. Foraging activity remained consistently low (median across birds of 0 – 21 % of the observation period) throughout the day (Figure 2b).

When these behaviors were examined during the control phase of the experimental period, we found that foraging behavior was similarly low (5.0 %, Q_{25} = 0.0 %, Q_{75} = 6.7 %), with no significant difference compared to the baseline period (estimate = 0.10, $z = 0.452$, $p = 0.652$). Whereas, though oral repetitive behavior remained relatively high (16.6 %, Q_{25} = 6.7 %, Q_{75} = 25.8 %), it was significantly lower than during the baseline period (estimate = -0.65, $z = -6.18$, $p < 0.001$).

Foraging interventions and their effect on behavior

Models containing forage condition as an explanatory variable explained the data significantly better ($\Delta AICc > 2$) than the null model for both foraging and repetitive behavior (Table S1). All four foraging interventions significantly increased the percentage of time spent foraging when compared to the control condition (Control: median = 5.0 %, Q_{25} = 0.0 %, Q_{75} = 6.7 %; Grass: median =28.3 % Q_{25} = 20.8 %, Q_{75} = 36.6 %, estimate = 2.37, $z=12.47$, $p < 0.001$; Millet discs: median = 31.6 %, Q_{25} = 10.0 %, Q_{75} = 39.2, estimate = 2.18, $z = 11.38$, $p < 0.001$; Baffle cages: median = 5.0 %, Q_{25} = 3.3 %, Q_{75} = 13.3 %, estimate = 1.06, $z = 5.10$, $p < 0.001$; Cucumber: median = 5.0 %, Q_{25} = 3.3 %, Q_{75} = 10.0 %, estimate = 0.60, $z = 2.73$, $p = 0.006$). The provision of grass and millet discs significantly decreased the expression of oral repetitive behavior compared to the control condition (Control: median = 16.7 %, Q25 = 6.7 %, Q75 = 25.8 %;Grass: median = 8.3 %, Q25 = 4.2 %, Q75 = 15.8 %, estimate = -0.63, z = -4.318, $p < 0.001$; Millet discs: median = 8.3 %, Q25 = 4.2%, Q75 = 16.7 %, estimate = -0.38, z = -2.775, $p < 0.001$).The provision of baffle cages and cucumber had no effect on oral repetitive behavior (Baffle cages: median = 15.0 %, Q25 = 6.7 %, Q75 = 19.2 %, estimate = -0.11, z = -0.85, $p = 0.397$; Cucumber: 13.3 %, Q25 = 10.0 %, Q75 = 29.2 %, estimate = 0.16, z = 1.31, $p = 0.191$) (Figure 3).

On the first day the duration of interaction with grass was a median of 19.5 minutes, this increased to a median of more than 50 minutes for the next two days, before falling to a median of 32.5 minutes on day 5. The duration of interaction with millet discs was also highest on days three and four (day 3 median = 63 minutes; day 4 median = 64 minutes).

Relationship between keeper usage score and behavior

Figure 5 shows the relationship between KS and the proportion of time spent performing behaviors across all of the RTBC. There was a significant positive relationship between KS and both the proportion of time spent interacting with the foraging item (Figure 5a, Table S2, estimate = 1.30, z value = 3.601, $P < 0.001$), and the proportion of time spent foraging (Figure 5b, Table S2, estimate = 1.42, z value = 3.55, $P < 0.001$). There was no significant relationship between KS and the proportion of time spent performing repetitive behavior (Figure 5c, Table S2, estimate = -0.92, z value = -1.23, $P = 0.194$). The KS for interaction with grass, baffle cages and cucumber discs corresponded with the duration of interaction (see above), but the KS for millet discs remained high despite the duration of interaction (see above) decreasing (Figure 4, Table S3).

Discussion:

This study demonstrates that providing foraging interventions can effectively decrease the amount of time spent performing oral repetitive behavior in a captive group of RTBC, corresponding with an increase in time spent foraging. During baseline and control conditions, the RTBC spent a median of less than 5 % of their day engaging in foraging activity (range: 0.0 – 6.7 %). Our two most successful interventions, grass and millet discs, significantly increased foraging during the observation period (08:30 - 15:50) to a median of 28.3 and 31.7 % respectively. This increase in foraging was consistent across birds (grass: range 16 – 46 %; millet discs: 23.3 – 46.6 %).

Oral repetitive behavior was significantly higher during baseline conditions than during control conditions (Figure 3). Stereotypic behavior as a consequence of feeding anticipation has been reported in many species (Robert et al., 2002; Swaisgood et al., 2001; Waitt & Buchanan-Smith, 2001). This may be likely in this case as prior to the study the RTBC were routinely given a low-calorie forage or other environmental enrichment when they were returned to the aviary following feeding. When this husbandry practice was ceased, the RTBC likely resorted to performing oral repetitive behaviors in anticipation of these food items. This may have also been exacerbated by the keepers providing birds in adjacent aviaries with these enrichment items. Behaviors such as beak grinding, tongue rolling or foot licking stimulate highly sensitive encapsulated nerve endings in the beak and tongue and, in tactile feeders such as parrots (Schneider et al., 2016), may serve as a self-soothing or 'coping' mechanism. This may be reflective of stress caused by a sudden change in husbandry during the initial baseline period.

During baseline conditions oral repetitive behavior peaked following the 12:00 and 15:00 free-flight bird shows and feeding (Figure 2). However, differences in foraging and oral repetitive behavior across time of day were noted between individuals (Figure S1). Most notably, the youngest female (Iranda, who was not flown in the free-flight bird show and who was acquired through the Taronga Wildlife Hospital) did not exhibit this pattern in behavior. This may suggest that the observed peak in oral repetitive behavior in the other RTBC may be an extended excitatory response following the free-flight bird show. However, this pattern in behavior was also observed on days that the bird show was cancelled. Thus, it is still likely that this behavior is due to the need to engage in extended foraging well beyond the capacity of the restricted diet. During the experimental period, individuals responded differently to each of the foraging interventions. While all subjects responded positively to grass and millet discs, only Iranda and Noko (a male) performed extended foraging behavior when baffle cages were presented. When grass was presented, Diyara (a female) completely ceased performing oral repetitive behavior where she would have ordinarily spent 40-100% of her time doing so. Thus, all individuals must be considered when designing an effective foraging enrichment strategy.

The success of grass and millet discs in this study may be attributed to an increase in time spent extracting and processing feed; in line with previous findings (Rozek et al., 2010; van Zeeland et al., 2013). When grass was presented, the RTBC would spend their time digging through the soil and extracting individual blades of grass, manipulating each blade with their feet and tongue. Similarly, the RTBC were required to grasp and manipulate the millet discs with their feet, and would spend time extracting the millet seeds from the flour mixture. Additionally, the thick consistency of the mixture contributed to an increased processing time, achieving a similar effect to increased pellet size (Rozek et al., 2010; van Zeeland et al., 2013). As a result, some individuals spent over an hour of each provision period interacting with these foraging interventions. In the wild, other cockatoo species spend 13 - 44 % of their day foraging (Sulphur crested cockatoos, Styche, 2000; glossy black cockatoos, Chapman & Paton, 2005; Carnaby's black cockatoos, Stock et al., 2013). Previous work by Zeeland et al. (2013) investigated the efficacy of eleven foraging interventions for captive Grey parrots (*Psittacus erithacus erithacus),* and found that interventions designed to increase extraction time (such as offering pellets in complex food reward devices) and food processing time (such as providing larger sized pellets) were the most effective strategies. Similarly; Rozek et al. (2010) demonstrated that Amazon parrots (*Amazona amazonica*) fed regular sized pellets spent 5.9 % of their daytime hours foraging, whereas parrots fed over-sized pellets spent 25.7 % of their day foraging, a figure that more closely resembled the activity budget of wild parrots.

An intervention is only successful if the animal is motivated to use it (Meehan & Mench, 2002; Rozek & Millam, 2011). For instance, Meehan and Mench (2002) demonstrated that providing continuous environmental enrichment may result in a decrease in the state of motivation for exploration. This corresponds with observations made in the present study where the duration of interaction for grass began to decline after the third week of provision (Figure 4). This suggests that certain interventions may require longer intervals between provisions to maintain motivation in the long term. This will require further exploration

Usage score assigned by keepers after the intervention had been removed from the enclosures was a useful proxy for the amount of time the RTBC, as a group, spent foraging during the provision period. However, the usage score was not significantly related to the proportion of time that the RTBC spent performing oral stereotypies, though the trend was in the predicted negative direction. The results suggest that this rapid assessment (keeper score) method is a reliable indicator of whether interventions are successful based on their ability to promote a specific behavior, in this case foraging. However, restrictions may apply in group-housing situations, where one or more individuals may ‘guard’ or otherwise prevent access to the foraging resources. In the present study, one individual (the youngest female) was observed antagonizing the other RTBC for their cucumber slices. Another male was observed biting and chasing other RTBC when utilizing the grass intervention. Despite this, we suggest that this method can be integrated into future management practices where similar interventions are provided; such that they can be ‘used up’ or would bear some other indication of the amount of time the RTBC spent interacting with the object. It is important to note however, that this method would only be effective for interventions that take a significant amount of time to be used up. For example, an intervention that could be consumed quickly would result in a high keeper score, but would not equate to a high duration of interaction. This method may only also be effective to a maximum group size where individual variability (i.e. individual preferences and use of different interventions) may be increased, and this would need to be investigated further.

It is important to determine whether there are daily patterns in behavior, particularly in the exhibition of ‘abnormal behaviors’, to develop an effective enrichment schedule that targets those problem periods. While observation times in this study were constrained by husbandry practices, it was clear that the RTBC would have benefited from foraging interventions after 16:00 when observations ended. Since the conclusion of this study, foraging interventions are now presented to the RTBC following their allocated feeding times, as this study indicated that the times following 13:00 and 15:30 were the greatest problem periods for the expression of oral repetitive behavior. Cucumber, baffle cages, grass and a modified millet disc (millet and gelatin disc) are still utilized, among a larger variety of enrichment items designed to encourage physical and oral manipulation, cognitive stimulation, sensory stimulation, and extended food extraction. A modified keeper scoring system has been successfully integrated, which allows keepers to record enrichment item usage and duration of interaction. Further studies which aim to determine the optimal intervals between repeated enrichment presentation (for example, weekly, fortnightly or other) should be performed to maintain maximal motivation for the RTBC to interact with each of the foraging interventions in the long term.

Conclusion

Overall, this study demonstrated that providing foraging interventions can effectively decrease the amount of time spent performing oral repetitive behavior in a captive population of RTBC, corresponding with an increase in overall time spent foraging. Here, two foraging interventions, grass and millet discs, were successful in both promoting foraging behavior and reducing oral repetitive behavior when compared to control conditions. Moreover, usage scores assigned by keepers effectively predicted the duration of interaction and time spent foraging when the interventions were present.

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The authors declare no conflicts of interest

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Tables

Table 1: Ethogram of recorded state behaviors

Category	Behavior	Description
Resting	Stationary	Sitting on a branch with the eyes open, or hanging from the enclosure walls
	Sleep	Perching with the eyes closed and the head turned back between the wings or hanging forward
	Ground	Sitting on the ground of the enclosure
Foraging	Environment directed foraging	Picking at edible feed on the ground, stripping bark from branches, stripping and chewing leaves and nuts from supplied browse
	Intervention directed foraging	Directly interacting with a foraging intervention, including; holding and eating cucumber slices, extracting feed from baffle cages, digging through soil and roots attached to grass, or manipulating millet pancakes and extracting millet seed
Locomotion	Fly/Flutter	Moving through the air or hopping between branches using wings
	Climb	Using the beak and feet to ascend or descend along branches/enclosure walls
	Walk	Moving along the ground or across perches using feet
Maintenance	Autopreen	Self-grooming, including: wiping their bill along a branch, moving their bill and tongue along their feathers, rubbing powder down, scratching head with foot or nibbling on feet
	Allopreen	Grooming of another bird
Oral repetitive	Self-directed	Oral behavior performed for at least 5-seconds without variation, including: beak grinding, tongue rolling or foot licking
	Metal-directed	Chewing, licking and manipulating the metal parts of the aviary, including the aviary walls, door frames and locks.

Table 2: Explanation of the keeper score (KS) for usage of the foraging intervention

Score	Definition
1	The forage had not been touched
2	The forage had been used minimally OR less than 1/3 of the provided forage had been consumed
3	The forage had been used moderately OR 1/3-2/3 of the provided forage had been consumed
4	The forage had been used substantially OR greater than 2/3 of the provided forage had been consumed
5	The forage had been used to its maximum potential OR all of the forage had been consumed

Figure Legends

Figure 1: Oral stereotypies were primarily self-directed in the form of repetitive foot licking (a). Four foraging interventions were provided to alleviate this; b) sliced cucumber, c) grass grown in pots and provided in clumps (also shown are fresh turf squares provided post-study in a similar manner), d) baffle cages, and e) millet discs.

Figure 2: Proportion of time spent performing a) resting and maintenance behaviors, and b) oral repetitive and foraging behaviors in RTBC across the day during baseline conditions. Five of the six birds were removed from their aviaries twice daily at 11:30 and 14:30 for performance in the free-flight bird show and/or feeding, and were returned at approximately 12:30 and 15:30 respectively; during these times observations were stopped. Data are presented as the median time spent performing behaviors at each point in time, arrows represent the difference between the first and third quartile (n = 6). Vertical dashed lines indicate timing of the bird show.

Figure 3: Proportion of time spent performing oral repetitive and foraging behavior in RTBC under baseline conditions (n = 10), and five foraging intervention conditions; no enrichment (control; n = 5), grass (n = 5), millet discs (n = 5), baffle cages (n = 5) and cucumber (n = 5). Data are presented as the daily median. Arrows represent the difference between the first and third quartile. Bars to the left of the vertical dotted line indicate no enrichment conditions. Asterisks represent values that are significantly different from the 'no enrichment' conditions.

Figure 4: Time spent interacting with a foraging intervention period under four foraging conditions; a) grass, b) millet discs, c) baffle cages, d) cucumber. Data are presented as the median duration of interaction of six RTBC over two 90-minute provision periods per day. Arrows represent the difference between the first and third quartile. The mean usage/consumption score for those provision periods is overlaid.

Figure 5: The relationship between the usage score and time spent; a) interacting with enrichment, b) performing foraging behavior, and c) performing oral repetitive behavior, per provision period for all foraging interventions at times where interventions were present (10:00-11:30 and 13:00-14:30).

Supplementary Figure Legends

Figures S1-S6: Proportion of time spent performing oral repetitive and foraging behaviors in individual RTBC across the day. Conditions are baseline (S1), control (S2), baffle cages (S3), cucumber (S4), grass (S5) and millet discs (S6). Individuals are three females (Diyara, Iranda and Nangari) and three males (Korridge, Noko and Tali). Data are presented as the median time spent performing behaviors at each point in time (n = 6). Vertical dashed lines indicate timing of the bird shows. Arrows indicate timing of foraging intervention provision (10:00 and 13:00 for 90-minute provision periods).

Table S1: Candidate models explaining behaviour ranked based on Akaike information criterion corrected to effective sample size (AICc) values calculated using the R package 'MuMIn'. Change in AICc, relative model weight, log likelihood (log (L)) and degrees of freedom are also included. The models include 150 observations of 6 individuals.

Table S2: Candidate models explaining behaviour ranked based on Akaike information criterion corrected to effective sample size (AICc) values calculated using the R package 'MuMIn'. Change in AICc, relative model weight, log likelihood (log (L)) and degrees of freedom are also included. The models include 150 observations of 6 individuals.

Table S3: Latency (minutes) to interact with each foraging intervention over five days of provision. Data is presented as the median latency of six RTBC to interact with the foraging interventions over two provision periods per day, and then the range (min,max) (n=12).