

Statistical assumptions and additional analyses

General statistical approach. Because movements of terrestrial animals cannot help being correlated in time and space, using conventional statistical tests to detect non-random patterns in movement decisions can be difficult for three reasons. First, local movements may be statistically non-independent, so analyses that rely on movements should either subsample data to avoid such dependence [1], or control for it in the statistical analysis by introducing an autocorrelation term [2]. Second, the expected effects of space and time on a series of positions should never be zero, unlike the null hypotheses of conventional statistical tests. Thus, observed dependencies of movements on distance or time need to be compared to those predicted from functional null models of the processes being studied [3].

The present analysis deals with these problems in several ways. The problem of autocorrelation of local movements between any two feeding sites is ignored in this analysis by considering each site-to-site move as a single segment; this simplification is justifiable given the very high linearity and directionality of movements between feeding sites [3]. To test for possible dependencies among movement segments between successive sites, I tested whether integrating decisions across two or three future sites [4] produced a better fit to the observed movements than did considering each site individually. To deal with the problem of irrelevant null hypotheses, I built on the approach used in previous experimental studies that tested for where-what memory [3]. I simulated foraging movements based on various movement rules which ignore elapsed time since the previous visit to a feeding site. The statistical effect of elapsed time in explaining simulated movements was compared for each model against the effect of elapsed time in explaining the observed movements.

To analyze the choice of the next feeding site, I used a multinomial logistic model. Such models are difficult to fit, and the various programs for the analysis of such data are constrained in several ways.

Although some routines in R (specifically, VGAM) can include random effects in the model of multinomial choice needed for this analysis, in practice these analyses failed to converge for the more complex models in this study. Therefore, I used the Choices Platform in JMP, which allowed inclusion of fixed effects for each choice site (a separate intercepts model) for all the analyses. Although using fixed effects instead of random effects is slightly less efficient, the qualitative results of fixed vs random-effects analyses were similar when both could be computed. When possible I used Firth Bias-adjusted estimates in fitting the models; these were not possible when including the sample period in the model.

Simple analysis

Distance to a feeding site, the site's renewal treatment and the elapsed time since a site was last visited all contributed significantly to explaining observed movement choices (Table S1).

Table S1. Multinomial regression of predictor variables on choice of next feeding site. I included the choice site as a predictor variable (to account for possible attractive qualities of each destination site that are not accounted for by the other predictor variables), but leaving it out does not change the qualitative result that all the other predictor variables have significant effects. The model uses Firth bias-adjusted estimates.

Variable	Parameter Estimate	Std Error	L-R ChiSquare	DF	Prob>ChiSq
choice site	(various)	(various)	65.171	7	<.0001*
ln(distance)	-3.96501383	0.2981571293	322.604	1	<.0001*
ln(interval)	0.86101637	0.0913304678	156.048	1	<.0001*
treatment	0.18815306	0.0951628293	3.933	1	0.0474*

Homogeneity of process. The purpose of the current analysis is to understand what characteristics of the feeding sites are used in making spatial choices. To ensure that each choice represents this process,

I eliminated a priori the choice made at the last site visited per day, since the monkeys ‘interpolated’ a visit to a sleeping site between that site and the first site visited the next day. Given that there is a relatively small number of used sleeping sites per home range in this area [5], the constraint of finding a sleep site might have caused the group to make spatial choices using criteria different from those used between feeding sites during the active period.

Because this analysis compares behaviors across two periods, within each of which the group needed to learn parameters of distinct treatments, it is important to ensure homogeneity of process within each treatment period, as well as (ideally) homogeneity of process between sample periods for variables that did not change (distance, time interval, preferences for individual choice sites). To test for homogeneity of process within each period, early samples (when animals might still have been learning the parameters of the treatment) were compared to later samples. The Choice model was as shown in Table S1, but included a subperiod indicator (early vs. later). When the early sample was taken as the first nine days of data collection, the subperiod variable produced highly significant results, but not when the early period was the first ten days. Thus, the initial nine days of data were excluded (for both treatment periods) to produce a pruned data set. Subsequent analyses of the pruned data set did not show a significant effect of subperiod when the subperiods were days 10-28 and 28-46 during the initial treatment period (Choice model: all LR Chi-Square values associated with the variable ‘subperiod’ were NS, $P \geq 0.22$).

To test for homogeneity of process across treatments for variables that did not change, I performed an analysis using the model reported in Table S1, but adding interaction terms for choice site, distance and interval, each crossed with the treatment period (first vs. second treatments). I did not include an interaction term for treatment itself because changes in treatment coincide exactly with two periods. There is little evidence that the monkeys’ decision criteria changed between the two sample periods (Table S2). The interaction terms for distance and elapsed interval were both very small, suggesting that

the monkeys evaluated these variables in making spatial decisions similarly across the entire experiment. The interaction term for choice site is significant, but it appears to duplicate or replace the treatment variable, which is severely reduced compared to the analysis without the interaction term (Table S1). This outcome is perhaps not surprising, given the much greater flexibility of the interaction term, which allows seven additional fitted parameters for choice site, relative to the treatment term, which allows only one. Regardless of the conflation between experimental treatment and possible temporal changes in site preferences, the monkeys show no evidence of changing how they treat elapsed time in choosing sites, which is the focus of this analysis.

Table S2. Multinomial regression of predictor variables on choice of next feeding site. This model did not use Firth bias-adjusted estimates, as doing so led to lack of parameter convergence.

Variable	Parameter Estimate	Std Error	L-R ChiSquare	DF	Prob>ChiSq
Choice site	(various)	(various)	61.024	7	<.0001*
ln(distance)	-6.21991864	0.698911	202.229	1	<.0001*
ln(interval)	1.16197748	0.15796	134.357	1	<.0001*
treatment	2.60511193	39.63875	0.028	1	0.866
Period*(Choice site)	(various)	(various)	16.592	7	0.02
Period*ln(distance)	0.01159939	0.698911	0	1	0.987
Period*ln(interval)	-0.00776994	0.15796	0.002	1	0.961

Three-step model

Based on suggestive results from the literature [4], I also tried a model of profitability that spatially integrated rewards across three sites instead of two (i.e., a ‘3-step look-ahead’ model rather than a ‘2-step look-ahead model’ [4]); I assigned the profitability of the most profitable triplet starting from any given destination site as the profitability for that destination site. This model, H4, did not perform

better than the two-step model H3 (T4 vs ST3, $P=0.47$), based on the bootstrap procedure used for the other tests.

Site-specific preferences

It is not clear why the capuchins preferred some sites over others, after accounting for the time- and treatment-sensitive profitabilities at each destination site. Sites differed in the details of presentation (exactly how high each platform was, how much canopy cover was over each platform, the habitat type of the site). These differences may have affected the perceived predation risk of visiting the various sites, but no explicit test of this hypothesis is possible with the current data. There is no obvious spatial pattern to the preferences – the sites with the highest and lowest estimated preferences (P100 and P400, respectively) are next to each other and both lie along the edge of a sudden change in topography, one of a series of levees that run parallel to the river's edge. The habitat surrounding a given site may also have affected the energy and time required to travel to it and thus modified the profitability relative to that calculated using the shortest-straight-line distance. I tested the travel-difficulty hypothesis by calculating the time of travel between pairs of sites and allowing for a destination effect. After correcting for distance to and expected reward at the chosen site, and time of day, the identity of the chosen site explained only a small amount of variation in the time taken to travel between sites, and sites associated with shorter residual travel times were not relatively more likely to be chosen ($r^2 = 0.0014$). Thus, it appears that more preferred choice sites were not faster to reach than were less preferred sites.

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