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BRIEF REPORT

Three Stones for Three Seeds: Natural Occurrence of Selective Tool Use by Capuchins (*Cebus libidinosus*) Based on an Analysis of the Weight of Stones Found at Nutting Sites

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Capuchins (*Cebus libidinosus*) occupy areas of Caatinga in northeast Brazil. They consume the nuts of several species of difficult-to-open fruits (two species of Palmae and one species of Euphorbiacea) and are reported to use stones as hammers to crack open the nuts. This article describes the weight of hammers found on anvils and presumably used for nut-cracking by individuals in two groups of wild unprovisioned capuchin monkeys. Hammer weights ranged from less than 200 to over 3 kg. Based on a correlation between the type of broken nuts found at a site and the stones present on anvils, there was evidence that hammer weight differed according to nut size. These findings are consistent with experimental data recently published by Visalberghi et al. [Current Biology 19, 2009, DOI: 10.1016/j.cub.2008.11.064] and indicate that capuchins are capable of choosing stones of appropriate weight to effectively use pounding tools in natural environments without interference from humans. Am. J. Primatol. 72:270–275, 2010.

Key words: capuchins; Caatinga; *Cebus libidinosus*; foraging behavior; manipulative skills; tool use

INTRODUCTION

Brown capuchin monkeys (*Cebus libidinosus*) have received increasing attention in the primatological literature, owing to what has been suggested as anatomical–behavioral convergences with chimpanzees, such as enlarged neocortex, manipulative and extractive foraging, and the ability to use tools [Visalberghi & McGrew, 1997]. Ottoni and Mannu [2002] and Fragaszy et al. [2004] were the first to systematically analyze tool use by semi-captive and wild *C. libidinosus* groups, respectively. Based on direct observation and physical evidence of nut-cracking (pitted depressions on anvils) in a semi-arid environment in Boa Vista- Piauí- northeastern Brazil, Fragaszy et al. [2004] described the capuchins' use of stones as percussive tools to crack open *Attalea* and *Syagrus* palm nuts. More detailed data analyses of the tool use sites conducted by Visalberghi et al. [2007] demonstrated that this is a common behavior in this population, and that capuchins selected tools of an appropriate weight and hardness for the task. Visalberghi et al. [2007] found that anvils were not randomly distributed, but were located near trees used as escape routes. The authors also reported a scarcity of stones that can be used as hammers in the area. Thus, the fact that stones of appropriate weight and hardness were found near anvil sites (on top or up to 30 cm from anvils) at a frequency greater than their overall distribution across the landscape indicates that capuchins transported them to tool use sites. According to these authors, the results indicate choice and planning by the capuchins during their tool-using behavior.

In a more recent study, Visalberghi et al. [2009] describe a series of tests in which eight wild capuchins (from a Boa Vista population) were experimentally faced with the opportunity of choosing between stone hammers of appropriate weight to crack nuts. All eight animals actively probed (by tapping) the stone before choosing the heavier stones when artificial hammers of the same size and appearance, but different weight were offered. All eight individuals performed above chance in their choice of appropriate stones for use as hammers.

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If *C. libidinosus* actively selects stones of particular size, weight, and hardness for a tool use task, then one should find differences in the weight of hammers used to crack open different sized nuts in the wild. In the this study, we report data collected on tool use choice in bearded capuchin monkeys' (*C. libidinosus*) at two sites in the Caatinga of Rio Grande do Norte, Brazil. Given that our capuchin study groups were not habituated, we examined evidence of tool choice based on the presence of cracked palm nuts and the distribution of hammer stones present on anvils. We argue that these capuchins naturally and spontaneously (i.e. in a nonhuman induced condition) choose stones based on the hardness of the nuts and the properties of the stone.

METHODS

Site

The Caatinga is a semi-arid area resulting from the retraction of the Amazonian forest during the Pleistocene [Oliveira et al., 2005]. It is characterized by abundant but irregular rainy periods and an aridity index (precipitation minus evapotranspiration) of less than 0.5 [Brasil, 2005]. This biome currently occupies most of northeastern Brazil (total area of 969.589 km^2) [Brasil, 2005], and is broadly classified as either arboreal Caatinga (trees 3–6 m high) or arbustive Caatinga (trees 1–3 m high with deciduous leaves) [Alves, 2007]. The areas occupied by capuchins in this study include hills of granitic Gaussianic origin where an abundance of stones and pebbles of all sizes are scattered on the ground. Ferreira et al. [2009] recently mapped the occurrence of *C. libidinosus* in two areas of Caatinga in western Rio Grande do Norte (RN): Martins (6°04′S, 37°54′W) and Luis Gomes (6°23′S, 38°22′W). A group of 53 *C. libidinosus* was observed in Martins and at least 40 individuals were observed in Luis Gomes. Both areas contain native vegetation interspersed with areas of human disturbance, such as corn crops and cattle crossings.

Data collection

Four 5-day visits to each site were conducted from June 2007 to December 2008, totaling 20 survey days at each site. A different subarea was surveyed each day to locate tool use sites, and subareas were resampled on subsequent visits ($N_1 = 4$ days survey in each subarea; $N_2 = 4$ subareas in each site). A total area of approximately 100 and 80 ha was surveyed in Luis Gomes and Martins, respectively. We considered tool use sites as being one or a number of small stones with wear marks (i.e. hammer) on top of larger stones also bearing wear marks (i.e. anvils), with cracked nuts/seeds on the anvil. We did not consider areas without cracked seeds as tool sites even when hammers and anvils were present. At each tool use site, we weighed the hammers using a digital jewelry scale with 1 g accuracy (ER2856st) and a maximum weight of 3 kg. We also scored the type of cracked seeds present. If more than one species of seed was found on top of an anvil, it was identified as a mixed site. Given the abundance of stones and pebbles in the vicinity, we assumed that stones that were successfully used to crack open nuts were more likely to be placed on the anvil; therefore, we weighed only hammers located on top of anvils. We acknowledge that this introduces a bias into our results because it is possible that the capuchins discarded, onto the nearby ground, stones that were used but not successful in accomplishing the task. After the seeds and putative stones used as hammers were weighed, they were removed from the top of the anvils to avoid weighing the same hammers in subsequent surveys.

Neither group was fully habituated to our presence, so nut-cracking behavior was not observed. However, we assume these are capuchin tool use sites used to crack open nuts because: (a) on three occasions we could actually hear the nut-cracking behavior and observe capuchins on the ground, but the animals climbed to the tree tops when we approached to within 20 m; (b) nuts of same genus are cracked by capuchins in Boa Vista [Piauí described by Fragaszy et al., 2004 and Visalberghi et al., 2007]; and (c) local residents report that they do not crack open these nuts.

Data were not normally distributed, so we used Kruskall–Wallis and Mann–Whitney nonparametric tests to determine whether hammer weight varied with the type of nut. We also conducted a hierarchical cluster analysis, an exploratory statistical procedure that forms data clusters based on the similarity of dependent variable's values. This test is robust to minor deviations from normality. We used hammer weight as the dependent variable to verify if the clusters formed would be composed of hammers used to crack open the same type of nuts.

All research conducted was in compliance with *American Journal of Primatology* guidelines for the ethical treatment of nonhuman primates, UFRN guidelines for animal care and use, and Brazilian legislation.

RESULTS

Different nuts were present at the two sites. At Martins, a total of 18 tool use sites were mapped, seven with cracked *Syagrus cearensis* (Palmae/Arecaceae) nuts, and eleven with cracked *Attalea oleifera* (Palmae/Arecaceae) nuts. At Luis Gomes, a total of 114 tool use sites were mapped, 42 with cracked *S. cearensis* nuts, 68 with cracked *Manihot dichotoma* (Euphorbiacea) nuts, and four with both *S. cearensis* and *M.t dichotoma* nuts. The size of these nuts differs considerably: 54 cm^3 for *A. oleifera*,

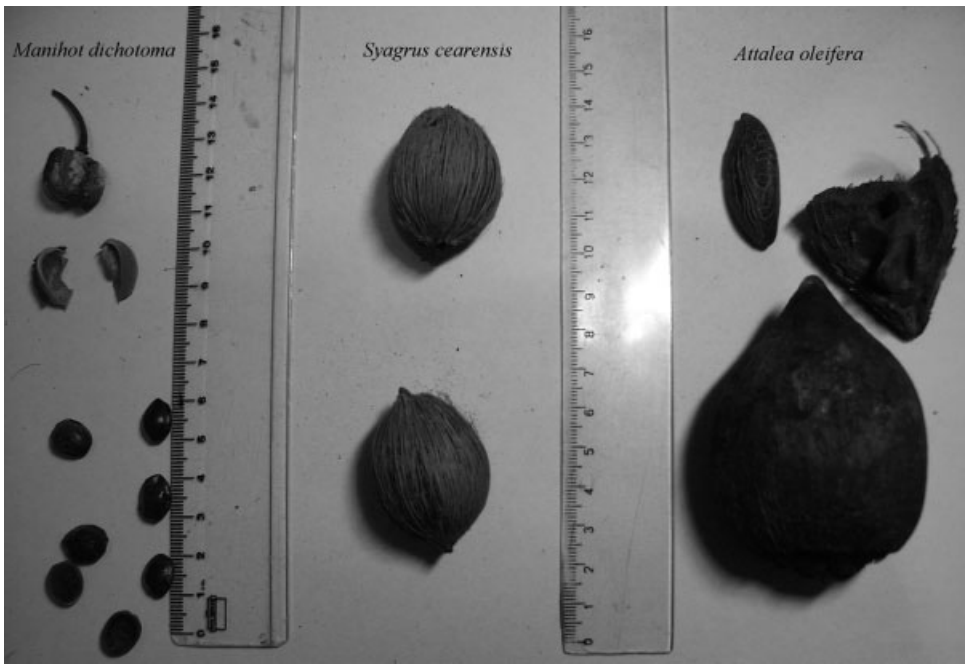

Fig. 1. Size of seeds consumed by capuchins (*C. libidinosus*) at Martins (*Attalea* and *Syagrus*) and Luis Gomes (*Syagrus* and *Manihot*).

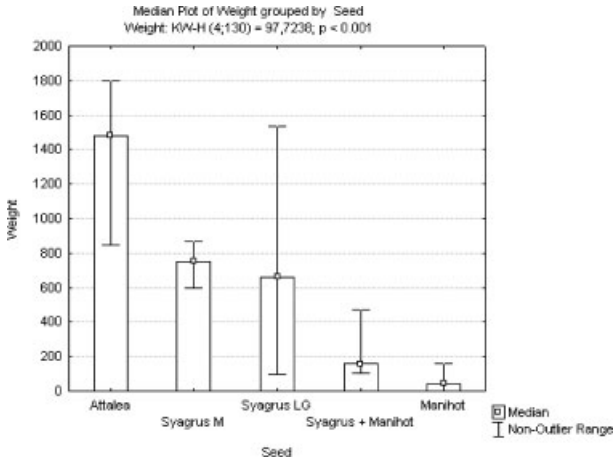

Fig. 2. Median and standard deviations of hammer weights found near different cracked nuts.

16 cm^3 for *S. cearensis*, and 0.24 cm^3 for *M. dichotoma* (Figs. 1 and 2).

Hammer weight analyses indicate that stones present on anvils varied according to the type of nut found (Kruskal–Wallis test: $H = 9.7238$, $df = 4$, $P = 0.001$), with all pairwise comparisons significantly different except for *Syagrus* at Martins and Luis Gomes, where hammer weights did not differ significantly (Mann-Whitney test: $Z = -0.383$, $N = 51$, $P = 0.702$). Mean (m) and median (md) hammer weights are shown in Table I.

Hierarchical cluster analyses with hammer weight as the dependent variable resulted in three clusters (Fig. 3), each composed mainly, but not exclusively, of just one type of seed: Cluster 1: *Syagrus*, Cluster 2: *Manihot*, and Cluster 3: *Attalea*. These results suggest that stones used by capuchins to crack different nuts also differed in weight

TABLE I. Mean and Median Weights of Stones Used as Hammers to rack Open Different Nuts

Type of nut and locality	Mean hammer weight (g)	Median hammer weight (g)	Standard deviation
Attalea Martins	1,414	1,483	335
Syagrus Martins	800	751	221
Syagrus Luis Gomes	887	667	488
Manihot Luis Gomes	65	45	71
Mixed site (*Syagrus*+*Manihot*) Luis Gomes	223	158	170

DISCUSSION

Two of the nuts consumed by bearded capuchins in the Caatinga of Rio Grande do Norte are from species of the same genera described by Fragaszy et al. [2004]: *Attalea and Syagrus* that are consumed by capuchin in Boa Vista (Piauí). The mean weight of stones used to crack open *Attalea* nuts (1,414 g) was almost twice that used to crack open *Syagrus* nuts (800–900 g). Moreover, stones found on anvils and presumably used to crack open *Manihot* nuts were almost 14 times lighter than those used to crack open *Syagrus* nuts, and 21 times lighter than those used to crack open *Attalea* nuts. These data suggest that

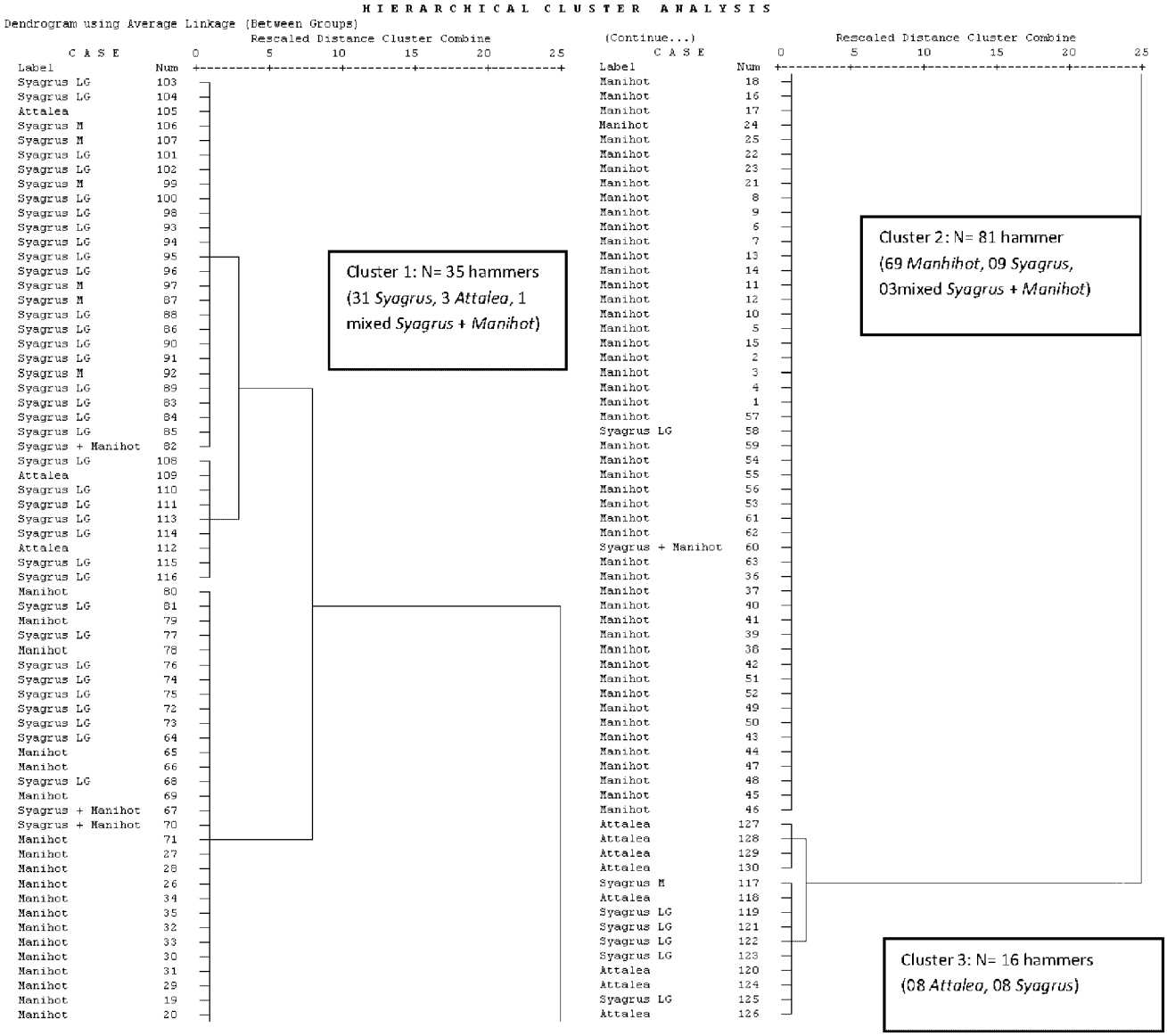

Fig. 3. Clusters formed based on hammer weight. *Y* axis shows type of seeds and number of tool use site. Hammer weight used as a dependent variable (values not shown). ''Rescaled Distance Cluster Combine'' indicates the distance between clusters based on Squared Euclidian Distance. As one moves to the right, relative distance becomes more apparent. The bigger the distances before two clusters are joined, the bigger the differences in these clusters. To find a membership of a particular cluster, simply trace backwards down the branches to the name.

capuchins are actively choosing appropriate stone to use as hammers based on tool weight. Although our results support the conclusions of observational and experimental studies of Visalberghi et al. [2007, 2009], we caution that because we did not directly observe the capuchins it is possible that stones present on the ground were used unsuccessfully (inappropriate weight) and then discarded. Thus, the exact nature of capuchin efficiency in using the most appropriate stones requires additional study.

We found differences in the weight of stones presumably used to crack open *Syagrus* at Luis Gomes. Hierarchical cluster analyses show three clusters composed mostly, but not exclusively, of one type of seed. This is expected because stones are abundant in both areas, and animals have a range of potential stones available to them. Although some stones may be more efficient in terms of foraging efficiency and number of pounding strokes required to obtain the food reward, it is likely that nut-cracking efficiency is relatively equal across a large range of stone weights. Moreover, we cannot discard the possibility of age, sex, or individual differences in tool-using ability or stone selection, and the fact that less experienced individuals may hone their tool use skills through trial and error.

According to Visalberghi et al. [2007], the mean hammer weight used by capuchins at Boa Vista (Piauí) to crack open nuts was 1,096 g (considering all hammering sites mapped during the study period). This value is within the range of the *Attalea* and *Syagrus* hammer weights found at our study site (Mean hammer weight in our study is 1,414 g for *Attalea* and 800 g for *Syagrus*). This difference in mean hammer weight found at Boa Vista and at our study sites may be due to the fact that (i) Visalberghi et al. [2007] lumped together the hammers of both nut types when presenting their results, making their reported hammer weight the mean hammer weight used to crack different seeds; (ii) at Boa Vista, capuchins use the same sites to crack both *Attalea* and *Syagrus* nuts, as that occurred at our mixed sites of *Syagrus* and *Manihot* nuts; or (iii) because there exists a different distribution of large stones at Boa Vista for animals to choose from. Similarly, Canale et al. [2009], studying tool use by wild *C. libidinosus* and *C. xanthosternus*, described that hammer weight ranged from 250 g to over 3 kg, but these authors did not classify hammer weight based on the type of seeds exploited. We also found stones weighing over 3 kg in sites used to crack *Attalea*; however, due to the upper limit of our scale, these stones were discarded from this analysis. It is noteworthy that neither Visalberghi et al. [2007] nor Canale et al. [2009] described the use of hammers lighter than 200 g, as was found at our study site.

Three species of capuchin monkeys have been described as using stones to crack open nuts in dry environments (Caatinga or Cerrado-Caatinga transitional areas): *C. libidinosus* [Fragaszy et al., 2004], *C. xanthosternus* [Canale et al., 2009], and possibly *C. flavius* [Emidio & Ferreira, 2009; Ferreira et al., 2009]. However, consumption of *Manihot* nuts was not described at other locations, although *Manihot* is a common genus in the Caatinga. Its consumption at Luis Gomes may be related to the absence of other larger nuts, such as *Attalea*, in the area. Tool use by capuchins has been argued to result from increased terrestriality and seasonal shortages in more easily accessible food types [Moura & Lee, 2004; Visalberghi et al., 2005].

One final remark regards the number of tool use sites found at our two study areas. Both areas are composed of patches of arboreal Caatinga, and both contain maize agricultural fields. At both sites the capuchins have been observed raiding corn. However, capuchins at Martins have more limited access to the ground because of large herds of cattle that range across the area, whereas capuchins at Luis Gomes are much less disturbed when traveling on the ground (at least during daylight periods because tracks of large cats were found in the area). Therefore, more restricted terrestriality may hinder tool use at Martins, as Visalgerghi et al. [2005] have suggested.

In conclusion, brown capuchins, *C. libidinosus*, that occupy areas of Caatinga in northeastern Brazil, are known to consume nuts of different sizes and use stones as hammers to crack open these nuts. The weight of hammers found on top of anvils significantly differed according to size of the nut. These naturalistic observations of tool use sites in which capuchins were not provided with nuts and stones suggest that these capuchins may choose differently weighted stones to open three types of nuts that differ significantly in size. However, because nut-cracking has not been observed directly, more detailed observational studies need to be conducted to confirm if capuchins are selecting appropriate tools for the specific foraging task (i.e. the right-sized stone for the right-sized nut) without interference from humans.

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REFERENCES

Alves J. 2007. Geoecologia da caatinga no semi-arido do nordeste brasileiro. Climatologia e Estudos da Paisagem 2:58–71.

Brasil. 2003. Biodiversidade da Caaatinga: áreas e ações prioritárias para a conservação. Ministério do Meio Ambiente, CD-ROM.

Brasil. 2005. Nova Delimitação do Semi-Árido Brasileiro. Brasília, Ministério da Integração Nacional, Secretaria de Políticas e Desenvolvimento Regional, CD-ROM.

Canole G, Guidorizzi C, Kierluff M, Gatto C. 2009. First record of tool use by wild populations of the yellow-breasted capuchin monkey (*Cebus xanthosternus*) and new records for the bearded capuchin (*Cebus libidinosus*). Am J Primatol 71:366–372.

Emidio R, Ferreira R. 2009. Tool use by *C. flavius* in caatinga. Poster presented at 46th Annual meeting of the Animal Behavior Society, Brazil.

Ferreira R, Jerusalinsky L, Silva T, Fialho M, Fernandes A, Roque A, Arruda F. 2009. On the occurrence of *Cebus flavius* (Schreber 1774) in the Caatinga, and the use of semi-arid environments by *Cebus* species in the Brazilian state of Rio Grande do Norte. Primates 50:357–362.

Fragaszy D, Izar P, Visalberghi E, Ottoni E, Oliveira MG. 2004. Wild capuchin monkeys (*Cebus libidinosus*) use anvils and stone pounding tools. Am J Primatol 64:359–366.

Moura A, Lee P. 2004. Capuchin stone tool use in Caatinga dry forest. Science 306:1909.

Oliveira P, Behling H, Ledru MP, Barberi M, Bush M, Salgado-Laboriau M, Garcia M, Medeanic S, Barth O, Barros M, Scheel-Ybert R. 2005. Paleovegetação e paleoclimas do quaternário do Brasil. In: Souza C, Suguio K, Oliveira A,

Oliveira P, editors. Quaternário do Brasil. Ribeirão Preto: Holos Editora. 2005. p 52–74.
Ottoni E, Mannu M. 2002. Semi-free ranging tufted capuchin monkeys (*Cebus apella*) spontaneously use tools to crack open nuts. Int J Primatol 22:347–358.
Visalberghi E, McGrew WC. 1997. *Cebus* meets *Pan*. Int J Primatol 18:677–681.
Visalberghi E, Fragaszy D, Izar P, Ottoni E. 2005. Terrestrality and tool use. Science 308:951.
Visalberghi E, Fragaszy D, Ottoni E, Izar P, Oliveira MG, Andrade FRD. 2007. Characteristics of hammers Stones and anvils used by wild bearded capuchin monkeys (*Cebus libidinosus*) to crack open palm nuts. Am J Phys Anthropol 132:426–444.
Visalberghi E, Adessi E, Truppa V, Spagnoletii N, Ottoni E, Izar P, Fragaszy D. 2009. Selection of effective Stone tools by wild bearded capuchin monkeys. Curr Biol 19. DOI: 10.1016/j.cub.2008.11.064.