ZOOBIOLOGY

Gum-feeder as environmental enrichment for zoo marmosets and tamarins

SCHOLARONE™
Manuscripts

Research highlights

- Wooden gum feeders can improve the welfare of zoo marmosets and tamarins by stimulating their natural species-specific behaviors and decreasing stress-related behavior. ~~and helping them to cope with stressful contexts~~.

- Zoo callitrichines, managed by adequate enrichment programs, may show positive welfare.

Regaiolli *et al.*

1

Title: Gum-feeder as environmental enrichment for zoo marmosets and tamarins

Short running title: Gum-feeder as enrichment for marmosets and tamarins

Authors: Regaiolli B.[1], Angelosante C.[2], Marliani G.[2], Accorsi P.A.[2], Vaglio S.[1,3,4] & Spiezio C.[1]

Institutional affiliations:

[1]Research and Conservation Department, Parco Natura Viva - Garda Zoological Park, Loc. Figara 40, 37012 Bussolengo, Italy

[2]Dipartimento di Scienze Mediche Veterinarie - Università di Bologna - Via Tolara di Sopra 50, 40064 Ozzano Emilia (BO), Italy

[3]Department of Biology, Chemistry and Forensic Science, University of Wolverhampton, Wulfruna Street, WV1 1LY Wolverhampton, UK

[4]Department of Anthropology & Behaviour, Ecology and Evolution Research (BEER) Centre, Durham University, South Road, DH1 3LE Durham, UK

Corresponding author:

Dr Stefano Vaglio

S.Vaglio@wlv.ac.uk

+44 (0) 1902 323328

Regaiolli *et al.*   2

Abstract

Tamarins and marmosets are small-bodied social callitrichines. Wild callitrichines feed on exudates, such as sap and gum;particularly, marmosets are mainly gummivores, while tamarins consume gums only occasionally and opportunistically. Zoo marmosets and tamarins are usually provided with gum Arabic as an alternative to the exudates normally found in the wild. The aim of this study was to evaluate the effects of a gum feeder on the behavior and well-being of four zoo-managed callitrichines. We studied four cotton-top tamarins (*Saguinus oedipus*), four red-handed tamarins (*Saguinus midas*), two pygmy marmosets (*Cebuella pygmaea*) and three Geoffroy's marmosets (*Callithrix geoffroyi*) housed at Parco Natura Viva (Italy). We conducted the study over two different periods, a baseline (control, without the gum feeder) and then a gum-feeder (when the gum feeder was provided) period. We used continuous focal animal sampling to collect behavioral data, including durations of social and individual behaviors. We collected 240 minutes of observations per period per study subject, with a total of 3,120 minutes for all the subjects in the same period and of 6,240 minutes in both periods. We analyzed data by using non-parametric statistical tests. First, we found that the gum feeder promoted species-specific behaviors, such as exploration, and diminished self-directed behaviors, suggesting an enriching effect on tamarin and marmoset behavior. Moreover, in red-handed tamarins, the provision of the gum feeder reduced the performance of self-directed and abnormal behavior, specifically coprophagy. These results confirm that gum-feeders are effective foraging enrichment tools for zoo marmosets and tamarins.

Keywords: zoo primate welfare, callitrichines, gum Arabic

1   **Introduction**

2   Tamarins and marmosets are small-bodied New World monkeys belonging to the subfamily of

3   Callitrichinae (Groves, 2001). They live in geographical areas ranging from Costa Rica to South Brazil,

4   Bolivia and Paraguay, with the greatest variety of species found in the Amazonian region (Emmons, 1990;

5   Buckner *et al.*, 2015). They are cooperative breeders and may form familial groups made up of a breeding

6   pair, several siblings and other members helping with parental care of the offspring. The breeding pair is

7   dominant over other group members (Emmons, 1990; Smuts *et al*., 1986).

8   The diet of wild tamarins and marmosets is affected by seasonality and availability of food

9   resources; they mainly feed on fruit, insects, small vertebrates, leaves and nectar (Rosenberger, 1992;

10   Garber, 1993; Bairrão Ruivo, 2010). In addition, their natural diet includes plant exudates, such as gum and

11   sap, which are rich in carbohydrates and minerals (Bairrão Ruivo, 2010; Power, 2010). Many plant gum

12   exudates consist of β-linked complex polysaccharides which often also contain glycoproteins and

13   proteoglycans (Gashua *et al.*, 2015) from which energy, water and minerals, particularly calcium, can be

14   obtained after fermentation. Callitrichines require a high intake of calcium from their diet, as these species

15   generally give birth to twins and plenty of milk is required during the nursing process (Garber, 1993*;* Kelly,

16   1993; Heymann and Smith, 1999; Pack *et al*., 1999; Passamani and Rylands, 2000; Taylor and Vinyard,

17   2004). The benefits of gum feeding have been widely investigated in the wild. Therefore, supplementing the

18   diet of zoo non-human primate species with plant gum exudates, might improve the diet and general well-

19   being of these primate species in captive environments (Garber, 1993*;* Kelly, 1993; Heymann and Smith,

20   1999; Pack *et al*., 1999; Passamani and Rylands, 2000; Taylor and Vinyard, 2004).

21   Plant gum exudates are an essential component of the marmoset diet, whilst it is less important for

22   other callitrichines (Power and Oftedal, 1996; Bairrão Ruivo, 2010; Power, 2010). For this reason,

23   marmosets show behavioral, morphological and metabolic adaptations to gum feeding. In particular, their

24   dental adaptations allow them to gouge trees and thereby stimulate gum exudate production as part of the

25   plants' response to wounding (Vinyard et al., 2003; Vinyard et al., 2004; Eng et al., 2009; Burrows & Nash,

26   2010); while modifications of the gastro-intestinal trait permit the digestion of gums and other plant exudates

27   (Coimbra-Filha and Mittermeier 1977; Heymann & Smith, 1999; Bairrão Ruivo, 2010). Tamarins tend to

28 feed on gum and sap only opportunistically, when this food is available in trees wounded by other animals,

29 with seasonal variation in terms of time investment for gum feeding (Garber, 1993; Power and Oftedal,

30 1996; Power, 2010).

31   Zoo tamarins and marmosets are generally provided with commercially available gum Arabic, as a

32 replacement for the various plant gum exudates that they consume in the wild (Goodrum *et al.*, 2000).

33 Furthermore, these plant gum exudates may be crucial biochemical digestive challenges for the normal

34 functioning of their digestive tract (Bairrão Ruivo, 2010). Wild tamarins show more frequent gum feeding

35 during the afternoon, as gum digestion is time consuming and would therefore be easier during the night

36 sleeping (Kelly, 1993; Heymann & Smith, 1999; Bairrão Ruivo, 2010). On the contrary, gummivore

37 marmosets are known to eat gum frequently throughout the daylight hours as their gastrointestinal system is

38 well-adapted to gum digestion (Kelly, 1993; Heymann & Smith, 1999; Bairrão Ruivo, 2010). Tamarins and

39 marmosets are usually attracted to novel objects, and vigilant and aware of what happens in their surrounding

40 environment (Menzel & Menzel, 1979). Promoting natural gum feeding behavior with specific devices might

41 be important to enhance the feeding strategy and husbandry of zoo-managed callitrichines in order to

42 improve their physical and mental well-being.

43   Giving zoo animals the opportunity to perform their species-specific behaviors represents one of the

44 primary goals of modern zoological gardens. In addition, ethological parameters have been proven to be a

45 valuable tool in assessing zoo animal welfare (Hill & Broom, 2009; Fontani *et al.*, 2014). The occurrence of

46 natural species-specific behaviors, such as exploratory behaviors, is considered an indicator of good welfare

47 status and enriched environment (Mench, 1994; Mellor & Beausoleil, 2015), while abnormal behaviors, such

48 as excessive inactivity, stereotypies and self-injurious behaviors, may indicate poor welfare or stressful

49 scenarios (Renner *et al.*, 2000; Manteca *et al.*, 2016). Moreover, self-directed behaviors such as self-

50 grooming and scratching, are usually benign activities that occur commonly in non-human primates

51 (Maestripieri et al., 1992). However, in certain situations such as social tension and conflicting or frustrating

52 contexts, self-directed behaviors can be associated with uncertainty and anxiety and have been considered as

53 displacement activities (Troisi & Schino, 1987; Troisi, 2002; Lutz, 2014; Spiezio *et al.*, 2017). Thus, a

54 decrease in self-directed behaviors might be considered as a positive welfare indicator, although these

55 activities are normally included and well-represented in the species-specific behavioral repertoire of primate

56 species (Spiezio *et al*., 2017; Leeds & Lukas, 2018). Similarly, coprophagy occurs in both captive and wild

57 non-human primates and may have an adaptive value in these species; however, in controlled environment

58 this behavior has been related to factors such as nutritional deficiency and medical problems but also

59 boredom and social stress (Krief *et al.*, 2004; Prates & Bicca-Marques 2005). Therefore, coprophagy has

60 been classified as an abnormal behavior and has been identified as a possible indicator of poor well-being

61 (*i.e.*, Prates & Bicca-Marques 2005; Lutz, 2018).

62   Environmental enrichment is a widespread practice among modern zoos and has been found to

63 promote the performance of species-specific behavioral repertoire and to address as well as prevent abnormal

64 behavior (Hosey *et al.*, 2013). Though some callitrichines may not require gum to reach their nutritional

65 needs in zoo settings, gum feeding may represent a behavioral necessity and could improve the diversity of

66 the behavioral repertoire as well as the welfare status of zoo marmosets and tamarins (Bairrão Ruivo, 2010).

67 In the current study, zoo tamarins and marmosets were provided with wooden drilled logs as gum-feeders.

68 Previous research investigating the effects of a similar gum-feeder on zoo marmosets and tamarins suggested

69 that this environmental enrichment could promote species-specific behaviors, reduce abnormal behaviors,

70 such as stereotypies and coprophagy, and decrease inactivity (McGrew et al., 1986; Roberts *et al.*, 1999;

71 Taylor, 2002; Huber & Lewis, 2011). In particular, the provision of hanging feeder baskets and sticks

72 smeared with Acacia gum promoted feeding and foraging while decreasing stereotypic behavior, specifically

73 excessive coprophagy, in red-handed tamarins in zoo (Taylor, 2002). Similarly, common marmosets

74 (*Callithrix jacchus*) in different social housing conditions have been found to benefit from foraging

75 enrichments, specifically gum feeders, promoting natural behaviors and leading to a reduction in the time

76 spent performing stereotypic behavior such as pacing (McGrew et al., 1986; Roberts *et al.*, 1999). In general,

77 providing zoo callitrichines with gum arabic in feeders that require specific feeding abilities has been found

78 to promote naturalistic behaviors and feeding strategies described in the wild. In particular, artificial gum

79 feeders are cheap and easy to build and can be helpful in enhancing the physical and mental well-being of

80 these species, which are well-disposed to work for gum, enhancing also the educative value of zoo exhibit

81 (McGrew et al., 1986; Huber & Lewis, 2011).

82   The aims of this study were to:

- Assess the effects of the gum-feeder on the behavior of two tamarin species *(Saguinus oedipus* and *Saguinus midas)* and two marmoset species (*Callithrix geoffroyi* and *Cebuella pygmaea)* which were scarcely investigated in the past. On the basis of prior work by other authors revealing that gum feeding represents a behavioral need and a digestive challenge for the digestive system of marmosets and, to a lesser extent, tamarins (Heymann & Smith, 1999; Bairrão Ruivo, 2010; Hosey *et al.*, 2013; Roberts *et al.*, 1999; Taylor, 2002), we predicted that the gum feeder would increase the performance of species-specific behaviors, such as explorative and feeding behaviors and reduce inactivity and abnormal behavior.

- Compare the duration of gum Arabic feeding between tamarins and marmosets, particularly the time spent feeding on gum between the morning and the afternoon within the two groups, to identify the optimal time for gum provision. Since gum digestion is time consuming and would therefore be easier during night sleeping, tamarins show gum feeding more during the afternoon (Heymann & Smith, 1999; Bairrão Ruivo, 2010). Thus, we expect that marmosets would perform gum feeding more than tamarins and during day time, while tamarins would eat gum during afternoon hours rather than in the morning.

Materials and Methods

Study subjects and area

We studied eight tamarins, specifically four cotton-top tamarins and four red-handed tamarins; and five marmosets, three Geoffroy's marmosets and a pair of pygmy marmosets. The study subjects belonged to two different age-groups: juveniles, including individuals aged less than two years (approximate age of sexual maturity, Tardif 1984; Ziegler et al. 1987; Abbott et al., 2003; Tardif et al., 2011) and adults, including individuals aged more than two years (Abbott et al., 2003; Tardiff et al., 2008; Tardif et al., 2011) **(Table 1)**.

All groups were housed at Parco Natura Viva-Garda Zoological Park (Bussolengo, Italy) in separated enclosures in the Tropical Green House. Although enclosures were not adjacent to each other, Geoffroy's marmosets, cotton-top tamarins and red-handed tamarins were in acoustic contact. Their enclosures were made of an outdoor and an indoor area and each area was approximately 30 m² and

111   contained trees, branches and logs, ropes, wooden boxes, sheds and shelves; the indoor areas were heated

112   and provided with UV lamps. The pygmy marmoset enclosure was an 18 m^2 aviary.

113   During the study, the gum feeders were placed in the outdoor area of the enclosures. Tamarins and

114   marmosets were fed twice a day with fruits, multi-cereal pap, mealworms, gum Arabic, and occasionally

115   meat and eggs. Fresh water was available *ad libitum*. Manipulative, sensory or food-related devices were

116   provided daily as environmental enrichment. The study, which did not involve any invasive or stressful

117   techniques, was conducted in accordance with the EU Directive 2010/63/EU and the Italian legislative

118   decree 26/2014 for Animal Research.

Procedure and data collection

120   The study was made of two different periods, the baseline and the gum-feeder period. During the baseline,

121   gum Arabic was provided in bowls at the time of the afternoon meal following the daily routine husbandry.

122   In the gum-feeder period, gum Arabic was provided, using the new gum feeders, at the usual feeding times

123   over the morning and the afternoon. The gum-feeder consisted of a wooden drilled disc, with 10 to 15 holes

124   each, on both sides of the disc **(Figure 1)**. The discs were hung with ropes on the enclosure trees and

125   branches, approximately 1.5 meters above the ground. The daily amount of gum Arabic was put in the holes

126   of the feeder. In particular, the amount of gum Arabic per subject was prepared using approximately 8 grams

127   of powder and 5 grams of water. The entire study consisted of 6,240 minutes (104 hours) of observation

128   divided in the baseline (52 hours) and in the gum-feeder period (52 hours) for all the subjects. Per period and

129   per subject, a total of 240 minutes of behavioral observations were carried out and two sessions per day per

130   monkey were run (one in the morning, one in the afternoon). The duration of the data collection sessions per

131   monkey differed between species based on the sample size. In particular, per period, data on each cotton-top

132   tamarin (N = 4) and on each red-handed tamarin (N = 4) were collected during eight 30-minute sessions. For

133   the marmosets, per period and per monkey, data were collected during six 40-minute sessions for Geoffroy's

134   marmosets (N = 3) and four 60-minute sessions for pygmy marmosets (N = 2) for an overall of 240 minutes

135   of observation for each subject within each period. Monkeys were observed in a prescribed sequence

136   following a specific design to avoid time-of-day bias in data collection. Feeding and enrichment times were

137   the same over the study period, one in the morning and one in the afternoon.

138   A continuous focal animal sampling method (Altmann, 1974) was used to collect durations of

139   normal and abnormal individual and social behaviors **(Table 2)**. The time spent out-of-sight, here defined as

140   "not observed", was also recorded. The red-handed tamarins were the only subjects to perform abnormal

141   behavior, specifically coprophagy, which was reported in three out of four monkeys, although for a very low

142   percentage of the total observation time (ranging from 0.13% to 1.67%). In order to assess the effect of the

143   feeder on the behavior of the red-handed tamarins, we created the category stress-related behaviors (SRB),

144   including coprophagy and self-directed behaviors. Although these behaviors are found in wild animals and

145   may be adaptive, they both have been related to stressful and conflict situations within controlled

146   environments (Troisi & Schino, 1987; Troisi, 2002; Prates & Bicca-Marques 2005; Lutz, 2014; Spiezio *et*

147   *al.*, 2017; Lutz, 2018). The gum-eating behavior was included in the category "feeding/foraging" as in the

148   first period gum Arabic was provided in bowls with other food; however, in order to compare the time spent

149   feeding on gum between marmosets and tamarins, the duration of gum feeding from the new feeder was also

150   collected **(Table 2)**.

151

Data analysis

153   Data were analyzed using non-parametric statistic tests and significance level was set at *p* < 0.05 (Siegel &

154   Castellan, 1992). In particular, the Wilcoxon test was used to compare the behavior of the study subjects

155   between the two periods (baseline *vs.* gum-feeder), whereas the Mann-Whitney test was used to compare the

156   time spent feeding on gum between the study groups (marmosets *vs.* tamarins) in the gum-feeder period.

157   StatView version 5.0 (SAS Institute Inc.) was used for all the statistical analyses on behavioral data. In

158   addition, single-case analyses were used to test the effect of the gum-feeder on the behavior of each

159   individual, comparing the performance of SRBs between different periods within each individual of red-

160   handed tamarins (Fisch, 2001) performing stress-related behaviors, specifically abnormal behavior and self-

161   directed behavior. For the single-case analyses, Wilcoxon-Mann-Whitney test (Marx *et al.*, 2016) was used.

162   For all behavioral categories, medians and interquartile range (IQR) are reported in the manuscript and

163   tables.

164

165   **Results**

166

Baseline vs. gum-feeder period

We investigated the effects of the gum-feeder on the behavior of the study subjects comparing the time spent

in individual and social behaviors as well as "not observed" between the two periods **(Figure 2, Table 3)**.

When considering each individual behavior, Wilcoxon tests revealed that feeding/foraging,

maintenance and self-directed were performed significantly more during the baseline than during the gum-

feeder period, whereas the opposite pattern was found for visual exploration. No other significant differences

were found (see **Figure 2** and **Table 3** for median, IQR and statistical values). On the other hand, within

social behaviors, interspecific behavior was performed more during the baseline than during the gum-feeder

period, whereas no other differences were found (see **Table 3** for median, IQR and statistical values).

Finally, Wilcoxon test revealed that "not observed" was performed significantly more during the baseline

than during the gum-feeder period ($z = -2.481$, $p = 0.013$) (**Table 3**).

Effect of the gum-feeder on tamarins

After evaluating the effects of the gum-feeder on all subjects, we focused on tamarins and marmosets

separately. Regarding tamarins, within individual behaviors, feeding/foraging and maintenance were

performed significantly more during the baseline than during the gum-feeder period, whereas no significant

differences were found in any other behavioral category (see **Table 3** for median, IQR and statistical values).

Effects of the gum-feeder on marmosets

Regarding marmosets, "not observed" was performed significantly more during baseline than during the

gum-feeder period ($z = -2.023$, $p = 0.043$), while no other significant differences were found between the two

periods (see **Table 3** for median, IQR and statistical values).

Effects of the gum-feeder on stress-related behavior in the red-handed tamarins

Three red-handed tamarins (CS, OB and Normann) showed the abnormal behavior 'coprophagy'. In order to

test whether the gum-feeder positively affected the behavior as a measure of welfare of these individuals, a

single-case analysis was done to compare the performance of SRBs between different periods within each

194   individual. For CS, the median duration of SRB was 113.5 (50) seconds in the baseline and 74.5 (51.25)

195   seconds in the gum-feeder period; for OB, the median duration of SRB was 90 (70.25) seconds in the

196   baseline and 52 (72.75) seconds in the gum-feeder period; for Normann, the median duration of SRB was

197   101 (99.75) seconds in the baseline and 60 (70) seconds in the gum-feeder period. Wilcoxon-Mann-Whitney

198   tests revealed that SRB were performed significantly more during the baseline than the gum-feeder period in

199   CS ($p = 0.037$) but no significant differences were found for OB and Normann ($p > 0.05$).

200

Gum-feeding in marmosets and tamarins

202   Finally, we focused on the time spent feeding on gum Arabic- by the study subjects. The median time spent

203   feeding on gum Arabic was 42.5 (90.8) seconds for tamarins and 235 (255.5) seconds for marmosets.

204   Marmosets tended to spend more time eating gum Arabic than tamarins ($U = 7$, $p = 0.056$). When

205   considering gum feeding during the day within each group, the median time spent feeding on gum Arabic by

206   tamarins was 31.5 (91.8) seconds in the morning and 0 (20) seconds in the afternoon. In the case of

207   marmosets, the median time spent feeding on gum Arabic was 116 (207) seconds in the morning and 114

208   (281) seconds in the afternoon. Wilcoxon tests revealed no significant differences between morning and

209   afternoon in both tamarins ($Z = -1.572$, $p = 0.116$) and marmosets ($Z = -0.365$, $p = 0.715$) **(Figure 3)**.

210

Discussion

212   This study aimed to investigate the effects of a gum-feeder, a wooden disc drilled with holes, on the behavior

213   of zoo tamarins and marmosets, to assess their welfare. Moreover, the study aimed to compare the time spent

214   feeding on gum Arabic between these species. First, each species interacted with the gum-feeders performing

215   a new behavior to obtain gum Arabic, confirming the enriching role on the animal daily routine and feeding

216   strategies of this device (McGrew et al., 1986; Roberts *et al.,* 1999; Huber & Lewis, 2011). All the study

217   monkeys interacted with the gum-feeder and showed the behavior of eating Arabic gum from the holes. In

218   particular, marmosets and tamarins had to cling on to the wooden disc holding with one or both hands and

219   then retrieve gum directly with the mouth or grasping it with one hand. When retrieving the gum, marmosets

220   gouged and scraped the disc moving the head and mouth similarly as in the tree-gouging behavior reported in

221   the wild: indeed, the jaws were widely open around the gum in the hole, the upper jaw anchored on the

222 wooden disc whereas the lower jaws indented the area around the hole, favoring both gouging and scraping

223 movements (Rylands, 1984; Vinyard et al., 2003; Vinyard et al., 2004; Burrows & Nash, 2010; Thompson *et*

224 *al.*, 2014). This movement was less pronounced in tamarins as they simply retrieved the superficial gum

225 coming out the holes and consumed it.

226 First, we found that subjects were out-of-sight ("not observed") more during the baseline than during

227 the gum-feeder period. This result seems to suggest that the gum-feeder could enhance the welfare of the

228 study subjects, engaging them in the performance of species-specific behaviors and increasing the time they

229 were visible to the public. This finding is consistent with previous research on gum-feeder provision in

230 marmosets, reporting an increased animal visibility(Kelly, 1993).

231 Regarding individual behaviors, when data on tamarins and marmosets were pooled together, we

232 found that feeding/foraging behaviors as well as maintenance behaviors were performed significantly less

233 during the gum-feeder period than during the baseline. Within each group (tamarins and marmosets), we

234 found the same patterns and significant differences for these categories in tamarins, whilst they did not differ

235 significantly in marmosets. Gum Arabic is a high-energy food source, rich in carbohydrates and minerals,

236 requiring longer time to be digested than other food items (Kelly, 1993; Power, 2010; Bairrão Ruivo, 2010).

237 It is possible that the provision of this food item in the new gum-feeder elicited tamarin and marmoset

238 interest, inducing them to eat gum Arabic before the rest of the food. Given the nutritional properties of the

239 gum (Power & Oftedal, 1996; Power, 2010), we speculate that a small amount of this food could be

240 sufficient for these small primates, leading to the reduction in the overall time spent feeding and foraging in

241 the second period. Also, it is possible that the interest toward the gum feeder as a novel device might supply

242 the callitrichines with the need of looking for food elsewhere in the enclosure (*e.g.* bowls, usual feeding

243 points). In other words, the study monkeys may have spent less time feeding and foraging in the second

244 period because they consumed gum Arabic first, and the same could extend to the decrease in maintenance

245 behavior during the second period. However, the presence of the gum feeder increased visual exploration,

246 which was performed significantly more during the gum-feeder period than during the baseline. This

247 behavior is particularly relevant in callitrichines as they are curious, attracted to novel objects and aware of

248 their surroundings (Menzel & Menzel, 1979). Such features of these small-bodied primates have been related

249 to improved vigilance and anti-predator behaviors (Caine, 1984). Therefore, the gum-feeder seemed to

Regaiolli *et al.* 12

250 encourage the performance of species-specific behaviors that are particularly important for the survival of

251 the species in the wild (Caine, 1984).

252 The presence of the gum-feeder also led to a significant decrease in self-directed behaviors, which

253 have been described as potential behavioral indicators of stress and anxiety in non-human primates, at least

254 in some situations (Maestripieri *et al.*, 1992; Leeds & Lukas, 2018). As our results underlined a decrease in

255 the performance of these behaviors, the presence of the gum-feeder seems to positively impact the behavior

256 of the study monkeys (Spiezio *et al.*, 2017; Leeds & Lukas, 2018). However, the study monkeys spent a

257 relatively low amount of time performing self-directed behaviors in both the baseline and the gum-feeder

258 periods (4% and 3% of the total observation time respectively) suggesting that this statistically significant

259 change may not necessarily be biologically important.

260 Regarding social behaviors, during the second period, a significant decrease of interspecific

261 behaviors, including interacting with or directing attention to humans was also reported. As visitors may be

262 distressing for the study subjects, this finding seems to highlight that the gum feeder might help tamarins and

263 marmosets to better cope with humans, promoting the performance of species-specific social behaviors and

264 discouraging possibly deleterious human-animal interactions. Together with the decrease in the time spent

265 out-of-sight in presence of the feeder, this result highlights a possible positive effect of gum-feeding devices

266 on callithricines' well-being in zoo environments.

267 Except for the decrease in feeding/foraging and maintenance behavior reported in the gum-feeder

268 period, no significant differences between periods were found in tamarins. The decrease in feeding/foraging

269 behaviors within tamarins seems consistent with the same result obtained when data from both species were

270 pooled together. Indeed, tamarins do not have as many adaptations for gum feeding and digestion as

271 marmosets (Heymann & Smith, 1999; Bairrão Ruivo, 2010; Hosey *et al.*, 2013; Roberts *et al.*, 1999; Taylor,

272 2002); therefore, consuming the gum before other food items due to the new presentation modality might

273 have reduced the tamarin appetite and the performance of other food-related behavior, but had no effect on

274 gummivore marmosets. However, the lack of significant differences in marmosets might be due to the small

275 sample size and thus further research is needed to better investigate this aspect.

276 On the other hand, marmosets were out-of-sight ("not observed") significantly more during the

277 baseline than the gum-feeder period, suggesting that for these species the presence of the drilled wooden

278 discs might help to increase the visibility of these species to zoo visitors. Inactive behaviors, such as

279 sleeping, were rather uncommon in the study subjects, as tamarins and marmosets tend to be very active

280 during the day. However, the study subjects had rest in the wooden nest boxes in the highest part of the

281 enclosure where the observer was not able to see them. Therefore, the behavioral category "not observed"

282 also included resting, which was otherwise not recorded in the study periods. For this reason, it is possible,

283 by decreasing the time spent out-of-sight, the presence of the gum-feeder also reduced inactive behavior of

284 the study subjects, especially within marmosets. This is consistent with findings by other authors on common

285 marmosets (*Callithrix jacchus*) (Roberts *et al.*, 1999).

286 When analyzing the behavior of each study subject during the two periods, we found that in three

287 red-handed tamarins, the gum-feeder had a positive effect as reduced SRBs, such as self-directed behaviors

288 and coprophagy. In addition, red-handed tamarins performed auto-coprophagy, which has been previously

289 related to physical or psychological stress in non-human primates (Anderson *et al.*, 1991; Krief *et al.*, 2004;

290 Prates & Bicca-Marques, 2005). One of the main effects of the gum-feeder was the reduction of SRBs,

291 including coprophagy. This was reported in other studies on gum-feeders in the red-handed tamarin,

292 suggesting that gum-related enrichment might be particularly relevant to prevent coprophagy in this species

293 (Taylor, 2002), and on laboratory common marmosets, where similar gum-feeding devices decreased

294 stereotypies (Roberts *et al.*, 1999).

295 Based on data collected during the second period, this study aimed at verifying the presence of

296 differences in gum-feeding between tamarins and marmosets and investigate whether the time spent feeding

297 on gum Arabic differed between morning and afternoon within each group. First, although no statistically

298 significant difference was found, marmosets tended to feed on gum more than tamarins. This finding agrees

299 with previous work on these species, as gummivore marmosets spend a large amount of time feeding on

300 gum, based on the importance of this food in their diet, whereas tamarins rely more on fruit and invertebrates

301 and cannot easily obtain and digest plant exudate (Kelly, 1993; Heymann & Smith, 1999; Bairrão Ruivo,

302 2010). However, it could not be excluded that the greater interaction of the marmosets with the feeder was

303 due to species differences in approaching the new enrichment devices, as previously suggested (Renner *et*

304 *al.*, 2000).

Regaiolli *et al.*

14

305   Similarly, no differences in time spent feeding on gum Arabic were found between mornings and

306   afternoons, neither within marmosets nor within tamarins. In the wild, marmosets feed on exudates

307   frequently throughout the daylight hours, as their gastrointestinal system is well-adapted to gum digestion

308   (Kelly, 1993; Heymann & Smith, 1999; Bairrão Ruivo, 2010). Therefore, the gum-feeding behavior of the

309   study Geoffroy's and pygmy marmosets resembles that reported in the wild, as the study subjects ate gum

310   Arabic to the same extent in both the morning and the afternoon. In the case of tamarins, these species are

311   known to eat exudates mainly during the afternoon, so that they can digest this food item overnight (Kelly,

312   1993; Heymann & Smith, 1999; Bairrão Ruivo, 2010). However, we collected data on the time spent eating

313   gum but not the amount of gum that was eaten. Again, providing gum in the new gum feeders might have

314   incentivized the consumption of this food item regardless of the time of the day.

315   Our findings seem to highlight positive effects of the gum-feeder on the behavior of zoo

316   callithrichines, as previously reported in the species considered in the current study as well as in other

317   species of marmosets and tamarins (McGrew et al., 1986; Roberts *et al.*, 1999; Taylor, 2002; Huber &

318   Lewis, 2011). However, the small sample size and the relatively small amount of data collected in our study

319   hamper the ability to draw firm conclusions and future research is needed to investigate more deeply the

320   gum-feeding behavior of zoo callithrichines, focusing on larger samples and longer periods of time.

321

Conclusion

323   In conclusion, our findings suggest that providing zoo tamarins and marmosets with gum Arabic in a

324   naturalistic and innovative way, such as using a wooden gum feeder, might enhance the welfare of these

325   species by:

326   1) promoting the performance of species-specific behaviors, such as visual exploration and decreasing

327   self-directed behaviors, that can in some cases indicate a stressful situation of the animal;

328   2) improving the visibility to zoo visitors by decreasing the time spent out-of-sight and in interspecific

329   interactions;

330   3) reducing the performance of abnormal behaviors, as reported in the study of red-handed tamarins;

331   4) increasing the consumption of this crucial food item, at least in the first stages of the introduction of

332   the feeder.

Regaiolli *et al.* 15

333 Our results add to previous literature on gum-feeding devices in tamarins and marmosets, highlighting that

334 the wooden gum feeders can improve the welfare of these species in controlled environments by stimulating

335 natural behaviors and promoting naturalistic feeding strategies (McGrew et al., 1986; Roberts *et al.*, 1999;

336 Taylor, 2002; Huber & Lewis, 2011).

337

Acknowledgements

Regaiolli *et al.*   16

References

347 Abbott DH, Barnett DK, Colman RJ, Yamamoto ME, Schultz-Darken NJ. Aspects of common marmoset

348 basic biology and life history important for biomedical research. Comp Med. 2003; 53:339–350.

349

350 Altman J. 1974. Observational study of behavior: sampling methods. *Behaviour* 49: 227-267.

351

352 Anderson, J. R., C. Combette, and J. J. Roeder. 1991. Integration of a tame adult female capuchin monkey

353 (*Cebus apella*) into a captive group. *Prim. Rep* 31:87–94.

354

355 Bairrão Ruivo E. 2010. *EAZA Husbandry Guidelines for Callitrichidae, 2nd edition*. Beauval Zoo.

356

357 Buckner JC, Lynch Alfaro J, Rylands AB, Alfaro ME. 2015. Biogeography of the marmosets and tamarins

358 (*Callitrichidae*). *Molecular Phylogenetics and Evolution*, 82: 413– 425.

359

360 Burrows AM, Nash LT. 2010. *The Evolution of Exudativory in Primates. Developments in Primatology:*

361 *Progress and Prospects.* Springer, NY.

362

363 Caine, N.G. (1984) Visual scanning by tamarins: a description of the behavior and tests of two derived

364 hypotheses. Folia Primatol. 43, 59–67

365

366 Coimbra-Filha AF, Mittermeier RA. 1977. Tree-gouging, exudate-eating, and the short-tusked condition in

367 *Callithrix* and *Cebuella*. In: Kleiman DC, editor. *The biology and conservation of the Callitrichidae.*

368 Washington DC: Smithsonian Institution Press, p 105-115.

369

370 Emmons LH. 1990. *Neotropical Rainforest Mammals: a Field Guide*. Chicago (US) and London (UK): The

371 University of Chicago Press.

372

373 Eng CM, Ward SR, Vinyard CJ, Taylor AJ. 2009. The morphology of the masticatory apparatus facilitates

374 muscle force production at wide jaw gapes in tree-gouging common marmosets (*Callithrix jacchus*). *Journal*

375 *of Experimental Biology*. 212(24): 4040-55.

376

377 Fisch GS. 2001. Evaluating data from behavior analysis: Visual inspection or statistical models. *Behavioural*

378 *Processes*. 54: 137-154.

379

380 Fontani S., Vaglio S., Beghelli V., Mattioli M., Bacci S. & Accorsi PA. 2014 Fecal concentrations of

381 cortisol, testosterone, and progesterone in cotton-top tamarins housed in different zoological parks:

382 relationships among physiological data, environmental conditions and behavioral patterns. *Journal of*

383 *Applied Animal Welfare Science* 17: 228-252.

384

385 Garber PA. 1993. Feeding ecology and behavior of the genus Saguinus. In: Rylands AB, editor. *Marmosets*

386 *and Tamarins: Systematic, Behavior, and Ecology*. Oxford (England): Oxford University Press.

387

388 Gashua IB, Williams PA, Yadav MP, Baldwin TC (2015) Characterisation and molecular association of

389 Nigerian and Sudanese *Acacia* gum exudates. *Food Hydrocolloids* 51: 405-413.

390

391 Goodrum LJ, Patel A, Leykam JF, Kieliszewski MJ (2000) Gum arabic glycoprotein contains glycomodules

392 of both extensin and arabinogalactan-glycoproteins. *Phytochemistry* 54:99–106.

393

394 Groves C. 2001. *Primate taxonomy*. Washington DC (US): Smithsonian Institute Press.

395

396 Heymann EW, Smith AC. 1999. When to feed on gums: temporal patterns of gummivory in wild tamarins,

397 *Saguinus mystax* and *Saguinus fuscicollis* (*Callitrichinae*). *Zoo Biology* 18: 459-471.

398

399 Hill, SP, Broom DM. 2009. Measuring zoo animal welfare: theory and practice. *Zoo Biology* 28:531–544.

400

Regaiolli *et al.*

18

401   Hosey G, Melfi V, Pankhurst S. 2013. *Zoo animals behavior, management and welfare*. Oxford (England):

402   Oxford University Press.

403

404   Huber, H. F. & Lewis, K. P. 2011. An assessment of gum-based environmental enrichment for captive

405   gummivorous primates. *Zoo Biology* 30: 71-78.

406

407   Kelly K. 1993. Environmental enrichment for captive wildlife through the simulation of gum feeding.

408   *Animal Welfare Information Center Newsletter* 4: 1-2, 5-10.

409

410   Krief, S., Jamart, A. and Hladik, C. M. 2004. On the possible adaptive value of coprophagy in free-ranging

411   chimpanzees. Primates 45: 141–145.

412

413   Leeds, A. & Lukas, K.E. (2018). Experimentally evaluating the function of self-directed behaviour in two

414   adult mandrills (*Mandrillus sphinx*). *Animal Welfare* 27(1): 81-86.

415

416   Lutz CK. 2014. Stereotypic behavior in non-human primates as a model for the human condition. *ILAR

417   Journal* 55: 284–296.

418

419   Lutz CK. 2018. A cross-species comparison of abnormal behavior in three species of singly-housed old

420   world monkeys. *Applied Animal Behavior Science* 199:52-58.

421

422   Maestripieri D, Schino G, Aureli F, Troisi A. 1992. A modest proposal: displacement activities as an

423   indicator of emotions in primates. *Animal Behaviour*, 44(5): 967-979.

424

425   Manteca X., Amat M., Salas M., Temple D. 2016. Animal-based indicators to assess welfare in zoo animals.

426   *CAB Reviews*, 11:1–10.

427

428 Marx, A.; Backes, C.; Meese, E.; Lenhof, H. P.; and Keller, A. (2016). EDISON-WMW: Exact Dynamic

429 Programming Solution of the Wilcoxon-Mann-Whitney Test. *Genomics Proteomics Bioinformatics,* 14(1):

430 55-61.

431

432 McGraw WC, Brennan JA, Russell C. 1986. An artificial gum tree for captive marmosets. *Zoo Biology* 5:

433 45-50.

434

435 Mellor, D. & Beausoleil, N. (2015) Extending the 'Five Domains' model for animal welfare assessment to

436 incorporate positive welfare states. Animal Welfare 24: 241-253.

437

438 Mench, J.A. (1994). Environmental enrichment and exploration. *Laboratory Animal,* 38-41.

439

440 Menzel, E. W., and Menzel, C. R. (1979). Cognitive, developmental and social aspects of responsiveness to

441 novel objects in a family group of marmosets (*Saguinus fuscicollis*). *Behaviour* 70: 251–279.

442

443 Pack KS, Henry O, Sabatier D. 1999. The insectivorous-frugivorous diet of the golden-handed tamarin

444 (*Saguinus midas midas*) in French Guiana. *Folia Primalogica* 70: 1-7.

445

446 Passamani M, Rylands AB, 2000. Feeding behavior of Geoffroy's marmosets (*Callithrix geoffroyi*) in

447 Atlantic forest fragment of south-eastern Brazil. *Primates* 41: 27-38.

448

449 Power ML. 1996. The Other Side of Callitrichine Gummivory. In: Norconk MA. Rosenberger AL,

450 Garber PA, editors. *Adaptive Radiations of Neotropical Primates.* Boston, MA, Springer,

451

452 Power ML (2010) Nutrional and digestive challenges to being a gum feeding Primates. In: Burrows A, Nash

453 L, editors. The evolution of exudativory in Primates. New York: Springer. 25–44.

454

Regaiolli *et al.*

20

455 Power ML, Oftedal OT (1996) Differences among captive callitrichids in the digestive responses to dietary

456 gum. Am. J. Primatol 40: 131–144.

457

458 Prates, HM, Bicca-Marques JC, 2005. Coprophagy in Captive Brown Capuchin Monkeys (*Cebus apella*),

459 *Neotropical Primates*, 13: 18-21.

460

461 Renner MJ, Feiner AJ, Orr MG, Delaney BA. Environmental enrichment for new world primates:

462 introducing food-irrelevant objects and direct and secondary effects. *J Appl Anim Welfare Sci* 2000;3(1):23 –

463 32.

464

465 Roberts RL, Roytburd LA, Newman JD. 1999. Puzzle feeders and gum-feeders as environmental enrichment

466 for common marmosets. *Contemporary Topics in Laboratories Animal Science*, 38(5): 27-31.

467

468 Rosenberger AL. 1992. Evolution of feeding niches in New World Monkeys. *American Journal of Physical

469 Anthropology* 88: 525–562.

470

471 Rylands AB (1984) Exudate-eating and tree-gouging by marmosets (Callitrichidae, Primates). In: Chavdwick

472 AC, Sutton SL editors. Tropical Rain Forest: The Leeds Symposium Leeds Philosophical and Literary

473 Society. 155–158.

474

475 Siegel S, Castellan N.J. 1992. *Statistica non parametrica*. Milano (IT). McGraw-Hill.

476

477 Smuts BB, Cheney DL, Seyfarth RM, Wrangham RW. 1986. *Primate Societies*. Chicago (US) and London

478 (UK): University of Chicago Press.

479

480 Spiezio C, Vaglio S, Scala C, Regaiolli B. 2017. Does positive reinforcement training affect the behaviour

481 and welfare of zoo animals? The case of the ring-tailed lemur (*Lemur catta*). *Applied Animal Behaviour

482 Science* 196: 91-99.

483

484 Tardif SD. 1984. Social influences on sexual maturation of female *Saguinus oedipus oedipus*. *Am J Primatol*

485 6(3): 199-209.

486

487 Tardif SD, Araujo A, Arruda MF, French JA, Sousa MBC, Yamamoto ME. 2008. Reproduction and aging in

488 marmosets and tamarins. In: Atsalis S, Margulis SW, Hof PR, editors. Primate Reproductive Aging.

489 Interdisciplinary Topics in Gerontology. vol 36. Basel: Karger;. pp. 29–48.

490

491 Tardif SD, Mansfield KG, Ratnam R, Ross CN, Ziegler TE. The marmoset as a model of aging and age-

492 related diseases. ILAR J. 2011;52: 54–65.

493

494 Taylor, T.D. 2002. Feeding Enrichment for Red-Handed Tamarins. *The Shape of Enrichment: A. Quarterly*

495 *Source of Ideas for Enrichmen*t 11(2): 1-3.

496

497 Taylor AB, Vinyard C. 2004. Comparative analysis of masseter fiber architecture in tree-gouging (*Callithrix*

498 *jacchus*) and non-gouging (*Saguinus oedipus*) callitrichids. *Journal of Morphology* 261: 276-284.

499

500 Thompson, C.L., M.M. Valença-Montenegro, L. César de Oliveira Melo, Y.B. Maranhão Valle, M.A.

501 Borstelmann de Oliveira, P.W. Lucas, and C.J. Vinyard (2014). Accessing Foods Can Exert Multiple

502 Distinct, and Potentially Competing, Selective Pressures on Feeding in Common Marmoset Monkeys.

503 *Journal of Zoology*, 294: 1-9.

504

505 Troisi A. 2002. Displacement activities as a behavioral measure of stress in non-human primates and human

506 subjects. *Stress* 5: 47-54.

507

508 Troisi A, Schino G. 1987. Environmental and social influences on autogrooming behaviour in a captive

509 group of Java monkeys. *Behaviour* 100: 292-302.

510

Regaiolli *et al.*

22

511   Vinyard CJ, Lucas PW, Valença-Montenegro MM, Melo LCO, Valle YM, Monteiro da Cruz MAO. 2004.

512   Where the wild things are: Linking lab and field work in studying tree gouging in common marmosets

513   (*Callithrix jacchus*). *American Journal of Physical Anthropology* 38: 200–201.

514

515   Vinyard CJ, Wall CE, Williams SH, Hylander, WL. 2003. Comparative functional analysis of skull

516   morphology in tree-gouging primates. *American Journal of Physical Anthropology* 120:153–170.

517

518   Ziegler TE, Savage A, Scheffler G, Snowdon CT. 1987. The endocrinology of puberty and reproductive

519   functioning in female cotton-top tamarins (*Saguinus oedipus*) under varying social conditions. *Biol Reprod*

520   37(3): 618-27.

188x176mm (150 x 150 DPI)

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Figure 1: The gum-feeder provided to marmosets and tamarins. In the gum-feeder period, tamarins and marmosets were provided with wooden drilled discs, hanged in the outdoor enclosure and filled with Arabic gum. The picture shows one of the study Geoffroy's marmoset interacting with the feeder.

188x176mm (150 x 150 DPI)
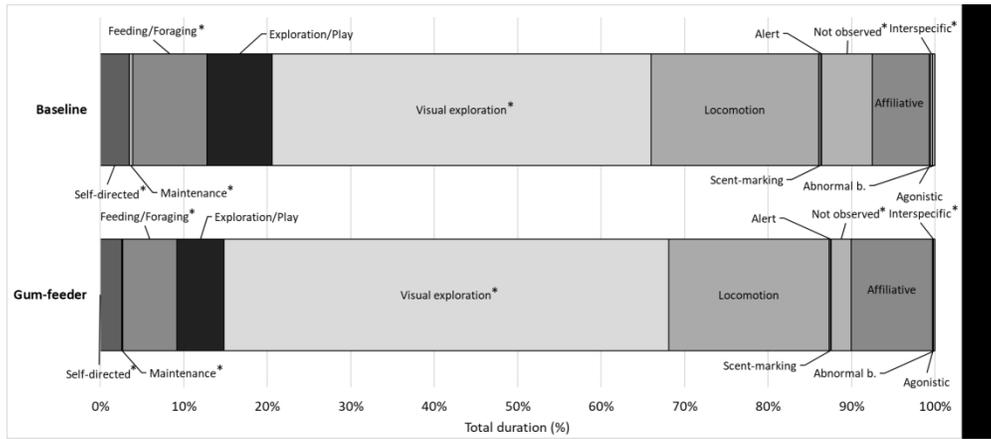
Figure 2: Behaviors of the study marmosets and tamarins. The bars report the % total duration in seconds of individual and social behaviors as well as "not observed" in the baseline and in the gum-feeder. Asterisks indicate categories that differed significantly between periods (Wilcoxon test: $p < 0.05$).

336x146mm (150 x 150 DPI)

Species	Name	Sex	Age
Cotton-top tamarin *(Saguinus oedipus)* *N = 4*	Mum	F	Adult
	Franca	F	Juv
	Rubik	F	Juv
	Dad	M	Adult
Midas tamarin *(S. midas)* *N = 4*	CS	F	Adult
	OB	F	Adult
	Norman	M	Adult
	CC	M	Adult
Geoffroy's marmoset *(Callithrix geoffroyi)* *N = 3*	Mum	F	Adult
	Dad	M	Adult
	Sbiru	M	Juv
Pygmy marmoset *(Cebuella pigmea)* *N = 2*	Peace	F	Adult
	Love	M	Adult

Table 1: Tamarins and marmosets involved in the study. For each species the table reports the

subject name, sex (F = female; M = male) and age class (Adult: > 2 years of age; Juv: < 2 years of

age).

Individual behaviours

Abnormal behaviour	Coprophagy.
Alert	Being watchful.
Exploration/Play	Exploring the environment, hunting, manipulating enrichment devices, leaves, twigs and other objects found in the enclosure by sniffing, biting, chewing, gouging, handling, pouncing on, grappling with.
Feeding/Foraging	Eating food found in the enclosure, either in bowls or foraging on trees, ground and other substrates.
Gum-feeder*	Eating gum from the gum-feeders (second period).
Locomotion	Moving around in the enclosure, walking, running or jumping along trees or walls of the enclosure
Maintenance	Peeing, defecating, drinking.
Scent-marking	Marking branches, shelves, ropes and other substrates with ano-genital, supra-pubic or sternal glands.
Self-grooming directed b.	Cleaning or licking the own hair or other parts of the body, scratching with the hands or with the legs.
Visual exploration	Looking around quietly.

Social behaviour behavior

Affiliative b.	Allo-grooming (using the hands and/or mouth to clean the partner fur or other parts of the body), being in contact with conspecifics, nuzzling (rubbing or pushing gently with the nose and mouth), anogenital inspection (orienting the face against or toward anogenital region of partner or use hands or mouth to investigate anogenital region of partner), stealing food/objects from the hands or from the mouth.
Agonistic b.	Fighting (biting, clawing, and wrestling), attacking (lunging at or pouncing on partner aggressively), cuffing, chasing, threatening (staring with lower eyebrows, furl brow, tongue flicking), mounting between same-sex individuals.
Interspecific b.	Interacting with or directing attention toward individuals of different species, such as humans (visitors, zoo-keepers zookeepers) or Azara agoutis (only in the Geoffroy's marmoset enclosure).

Not visible

Not observed	The individual is not visible to the observer or it is not possible to identify the behaviour behavior being performed.

*This behavioural category was recorded only in the second period, when Arabic gum arabic was put in the gum feeder and it was possible to detect clearly that the subjects were feeding on that food item.

Table 2: Study ethogram. Individual and social behaviours collected in the study periods.

	All			Tamarins			Marmosets		
Individual behavior	**Baseline**	**GF**	**Z and p-value**	**Baseline**	**GF**	**Z and p-value**	**Baseline**	**GF**	**Z and p-value**
Abnormal	0 (0)	0 (9)	#	0 (60.8)	0 (79.5)	#	0 (0)	0 (0)	#
Alert	7 (17.5)	0 (4.5)	$z = -1.868$, $p = 0.062$	8 (15.8)	4 (9.5)	$z = -1.016$, $p = 0.310$	5 (18.5)	0 (0)	$z = -1.826$, $p = 0.068$
Expl/play	869 (1307.5)	663 (612)	$z = -1.922$, $p = 0.055$	974.5 (1569.5)	857.5 (1308.5)	$z = -1.400$, $p = 0.161$	321 (1509)	494 (723.5)	$z = -1.214$, $p = 0.225$
Feeding/Foraging	1219 (590.5)	826 (665.5)	$z = -2.481$, $p = 0.031$*	1312.5 (635.3)	1233.5 (864.5)	$z = -2.100$, $p = 0.036$*	1081 (653.5)	763 (485.5)	$z = -1.483$, $p = 0.138$
Locomotion	2920 (980.5)	2859 (1572.5)	$z = -0.384$, $p = 0.701$	2958.5 (890.3)	3340.5 (1155.8)	$z = -2.260$, $p = 0.208$	2920 (1199.5)	1622 (1432)	$z = -1.483$, $p = 0.138$
Maintenance	57 (70)	10 (32)	$z = -3.111$, $p = 0.002$*	83 (42.8)	13 (30.5)	$z = -2.521$, $p = 0.012$*	19 (11.5)	0 (22.5)	$z = -1.761$, $p = 0.078$
Scent-marking	38 (36.5)	22 (28.5)	$z = -1.049$, $p = 0.294$	27.5 (36)	28 (32.8)	$z = -0.491$, $p = 0.624$	49 (55.5)	19 (37)	$z = -0.944$, $p = 0.345$
Self-~~grooming~~directed	420 (240.5)	392 (337)	$z = -2.201$, $p = 0.028$*	464 (257.3)	437.5 (183.3)	$z = -1.260$, $p = 0.208$	384 (250.5)	208 (354)	$z = -1.753$, $p = 0.080$
Visual expl	6891 (2946.5)	8097 (1760)	$z = -2.201$, $p = 0.028$*	6578 (3024.8)	7860.5 (2860.3)	$z = -1.680$, $p = 0.093$	7080 (2402.5)	8119 (2034)	$z = -1.483$, $p = 0.138$
Social behavior									
Affiliative	764 (632.5)	1331 (1180.5)	$z = -1.712$, $p = 0.087$	704.5 (753.5)	776.5 (798.8)	$z = -0.560$, $p = 0.575$	1110 (964)	1797 (1269.5)	$z = -1.753$, $p = 0.080$
Agonistic	0 (34.5)	8 (28.5)	$z = -0.533$, $p = 0.594$	9.5 (43.3)	7 (20.8)	$z = -0.280$, $p = 0.779$	0 (21.5)	8 (54.5)	$z = -1.604$, $p = 0.110$
Interspecific	0 (69)	0 (0)	$z = -2.023$, $p = 0.043$*	0 (59.3)	0 (0)	$z = -1.342$, $p = 0.180$	38 (94)	0 (0)	$z = -1.604$, $p = 0.110$
Not observed	956 (881.5)	207 (553.5)	$z = -2.481$, $p = 0.013$*	724.5 (846.5)	172 (633)	$z = -1.540$, $p = 0.124$	1117 (740)	303 (615)	$z = -2.023$, $p = 0.043$*

*Significant difference between the two periods ($p < 0.05$).

Table 3: Individual <u>behaviors, </u>~~and~~ social behaviors <u>and "not observed" </u>in the baseline and in the gum-feeder period. For each behavioral category, the table reports the median (interquartile range) duration in seconds calculated in the baseline and in the gum-feeder period (GF), as well as the *z* and *p* values of the Wilcoxon test performed to compare the two periods. All: data collected on different species pulled together; Tamarins: analysis performed within the tamarin group (N = 8) (*Saguinus oedipus, Saguinus midas*); Marmosets: analysis performed within the marmoset group (N = 5) (*Callithrix geoffroyi, Cebuella ~~pigmea~~<u>pygmaea</u>*).