



Mantled howler monkeys (*Alouatta palliata*) show no preferential hand use in two self-directed behaviors

Ricardo J. Ortíz-Zárate¹ · Ariadna Rangel-Negrín¹ · Alejandro Coyohua-Fuentes¹ · Jurgi Cristóbal-Azkarate² · Pedro A. D. Dias¹

Received: 16 January 2024 / Accepted: 30 May 2024
© The Author(s), under exclusive licence to Japan Monkey Centre 2024

Abstract

Hand preference is the preferential use of one hand for a single task. Its study provides insight into the neural mechanisms underlying motor skills, perception, and cognitive functions. From a comparative perspective, it also offers a window into evolutionary history, shedding light on whether manual preferences stem from genetics, environmental influences, or a combination of both. However, there is a paucity of information on preferential hand use for several primate taxa. Here we examine hand preference for the first time in mantled howler monkeys (*Alouatta palliata*) to determine if there is preferential hand use at the individual and population level as well as sex differences in hand use. We followed 17 wild adult individuals for 10 months and used focal animal sampling (506 focal samples) to record hand use in two types of self-directed behaviors, touching (1246 events) and scratching (1115 events). According to the binomial tests, four individuals were right-hand-preferent, two were left-hand-preferent, and 11 were ambilateral during touching, whereas for scratching seven individuals were right-hand-preferent, two were left-hand-preferent, and eight were ambilateral. At the population level, there was ambilaterality in both behaviors. At the individual level, according to the HI index, hand preference in touching and scratching were not associated and did not vary between sexes. These findings concur with previous studies with howler monkeys and other taxa suggesting that population-level hand preference is not a universal trait across primates.

Keywords Handedness index · Laterality · Platyrrhines · Scratching · Touching

Introduction

Lateralized behavior, exhibited as preferential hand use in humans, has also been observed in numerous animal species, including fish, amphibians, reptiles, birds, and mammals (e.g., Bisazza et al. 1997; Hoso et al. 2007; Ehret 1987). Understanding lateralized behavior through preferential hand use provides insight into the neural mechanisms governing motor skills, perception, and cognitive functions (Fitch and

Braccini 2013). From a comparative perspective, it also offers a window into evolutionary history, shedding light on whether manual preferences stem from genetics, environmental influences, or a combination of both (McGrew and Marchant 1998).

Several primate species show preferential hand use at the population level, such as chimpanzees (*Pan troglodytes*; Hopkins et al. 2004; Lonsdorf and Hopkins 2005), rhesus macaques (*Macaca mulatta*; Westergaard et al. 1998), baboons (*Papio anubis*; Vauclair et al. 2005), Hanuman langurs (*Semnopithecus entellus*; Dutta et al. 2024), and black-striped capuchins (*Sapajus libidinosus*; de Andrade and de Sousa 2018). However, rather than being a static trait, hand preference can vary with age (e.g., Westergaard and Suomi 1993), sex (e.g., Milliken et al. 1991), the complexity of the manual task being performed (Fagot and Vauclair 1991), and species. For instance, bonobos (*Pan paniscus*) show population-level left-hand bias in complex tasks, such as carrying objects, and a population-level right-hand bias to initiate locomotion (Hopkins

✉ Ricardo J. Ortíz-Zárate
ricardojesus.ortiz@upaep.mx

✉ Pedro A. D. Dias
pedroaddias@gmail.com

¹ Primate Behavioral Ecology Lab, Instituto de Neuro-Etología, Universidad Veracruzana, Av. Dr. Luis Castelazo Ayala S/N, CP 91190 Xalapa, México

² Department of Basic Psychological Processes and Their Development, University of the Basque Country, Donostia, Spain

and de Waal 1995). Chimpanzees (*P. troglodytes*) exhibit hand preference at the individual level both when reaching for food and in complex tasks (Collel et al. 1995). Nevertheless, neither ape species shows hand preference in self-directed behaviors such as touching body and face/head at the population level (Aruguete et al. 1992; Hopkins et al. 1993; Hopkins and de Waal 1995), while orangutans (*Pongo pygmaeus pygmaeus*) use their left hand preferentially for such tasks at the population level (Rogers and Kaplan 1996), but show no population-level hand preference for complex tasks, like reaching out and taking food items, and manipulating food items with fine finger movement. In addition, characteristics like arboreal lifestyle and vertical posture may demand asymmetries in hand use (MacNeilage 1991), and tool use is related to hand preference due to the skills required for their manipulation (van Schaik et al. 1999).

While investigating the variability of preferential hand use within and across primate species offers valuable insights into the evolutionary pressures that might have shaped these preferences (Fitch and Braccini 2013; McGrew and Marchant 1998) and associated neurological structures (e.g., Cooper 2006), at the moment there is a paucity of information on preferential hand use for several primate taxa. Such is the case of howler monkeys (*Alouatta*), a platyrrhine genus of at least 12 species and for which there is a single study on preferential hand use (Sfar et al. 2014). That study reported no hand preference at the population level among 12 captive red howler monkeys (*A. seniculus*; five adult females, three adult males, two juvenile females, one female infant, and one male infant) during reaching-for-food tasks. In the current study, we focused on mantled howler monkeys (*A. palliata*) to further our understanding of inter-specific variation in primate preferential hand use.

Although howler monkeys are arboreal primates, a lifestyle that may lead to asymmetrical postures that favor lateralization (MacNeilage 1991), they do not: (i) use tools; (ii) manipulate their environment, aside from foraging (Milton 1980) and while displaying behaviors like branch shaking or branch breaking, which is rare (Jones and Van Cantfort 2007); and (iii) have very low rates of overt social interactions (Crockett and Eisenberg 1987). Given that these traits should not favor the emergence of hand preferences (Prieur et al. 2019), we hypothesized that mantled howler monkeys are ambilateral. To test this hypothesis, we focused on self-directed behaviors, which have been used in previous studies to assess hand preference in primates (Aruguete et al. 1992; Hopkins et al. 1993; Hopkins and de Waal 1995; Rogers and Kaplan 1996), and can be reliably observed in free-ranging howler monkeys. We predicted no hand preference in self-directed behaviors (touching and scratching) at both the individual and the population level, and that there are no differences between sexes in hand preference.

Methods

Study site and subjects

We conducted the study at La Flor de Catemaco, a ca. 100-ha forest fragment located in Los Tuxtlas (Mexico, 18°26'43'' N, 95°02'49'' W). Mantled howler monkeys living in this area have been studied since 2002 and are habituated to the presence of researchers (Dias et al. 2023). We studied 17 adults (ten females and seven males) belonging to two neighboring groups that we individually recognized by natural markings in the fur and other physical traits, such as scars, broken fingers, and facial features.

Behavioral sampling

Between July 2022 and April 2023, we used focal-animal sampling with continuous recording for 1-h periods (Altmann 1974) to assess all occurrences of two self-directed behaviors, touching (contact between the hand and any part of the body) and scratching (repetitively rubbing the skin with a hand). We collected 506 focal samples, with a mean \pm SD of 29.8 \pm 9.6 observation hours per individual.

Data organization and analysis

To avoid bias in hand use associated with difficulty in accessing certain body areas (e.g., back), we considered for analysis only touches and scratches directed at the frontal plane area of the body. We also excluded from analysis actions that obligatorily require the use of a specific hand (e.g., the right forearm can only be scratched with the left hand) and events in which one of the hands was involved in a competing task (usually support).

We calculated the handedness index (HI) per individual (Hopkins 2013) as $HI = (R - L)/(R + L)$, in which R is the number of right-handed actions and L is the number of left-handed actions. HI varies between 1 and -1, with positive values indicating right-hand preference and negative values, left-hand preference (Hopkins 2013). We calculated HI per individual and across individuals (i.e., population-level HI) for the two behaviors. We then used: two-tailed binomial tests to classify individuals as left-hand-preferent, right-hand-preferent, or ambilateral based on the frequencies of hand use; one-sample *t* tests on HI indices to determine population-level hand preference; assessed consistency in HI between touching and scratching with a Spearman correlation; and examined differences between sexes in HI with Mann–Whitney tests.

Results

We recorded a total of 1246 touches and 1115 scratches, with an average \pm SD of 73.3 ± 31.2 touches and 65.6 ± 27.7 scratches per individual. According to the results of binomial tests, four individuals were right-hand-preferent, two were left-hand-preferent, and 11 were ambilateral for touching, whereas for scratching seven individuals were right-hand-preferent, two were left-hand-preferent, and eight were ambilateral (Table 1). At the population level, there was ambilaterality in both touching ($t(16) = 1.43, P = 0.171$) and scratching ($t(16) = 1.03, P = 0.328$). HI indices per individual were not consistently associated between touching and scratching ($r_s = 0.10, n = 17, P = 0.701$; Fig. 1), and there were no significant differences between sexes in HI indices (touching HI $W = 41, P = 0.591$; scratching HI $W = 31, P = 0.732$; total HI $W = 34, P = 0.961$).

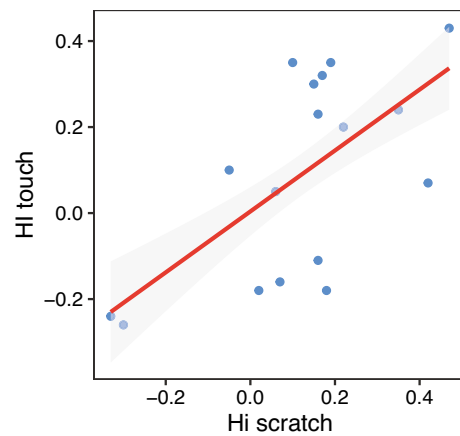


Fig. 1 Association between handedness indices (HI) of 17 mantled howler monkeys in two self-directed behaviors, touching and scratching

Discussion

We examined preferential hand use in wild mantled howler monkeys in the context of two self-directed behaviors, touching and scratching. Although some individuals showed hand preference, as expected, there was no consistent preferential

hand use at the population level nor differences between sexes in hand preference. Hand preference at the individual level was also not comparable between behaviors, with very few individuals consistently preferring their right or their left hand across the two tasks studied here. These findings concur with previous studies in howler monkeys and other taxa suggesting that handedness is not an universal trait across

Table 1 Frequency of behaviors performed with left and right hands, Handedness Index (HI), and hand preference according to binomial test results in mantled howler monkeys (*Alouatta palliata*) in two self-directed behaviors

Subject	Sex	Touching			Scratching		
		L:R	HI	Hand preference ^a	L:R	HI	Hand preference ^a
HI	Female	13:14	0.04	A	10:21	0.35	R
HA	Female	20:49	0.42	R	38:39	0.01	A
HB	Female	28:15	-0.30	L	46:26	-0.28	L
HCC	Female	23:24	0.02	A	16:34	0.36	R
HF	Female	33:31	-0.03	A	25:45	0.29	R
HN	Female	14:9	-0.22	A	6:15	0.43	R
HPG	Female	36:51	0.17	A	46:90	0.32	R
HPM	Female	34:47	0.16	A	76:61	-0.11	A
HS	Female	28:29	0.02	A	42:30	-0.17	A
HSp	Female	38:44	0.07	A	32:23	-0.16	A
M2	Male	23:48	0.35	R	26:42	0.24	R
MCN	Male	58:84	0.18	R	58:44	-0.14	A
MJ	Male	36:41	0.06	A	37:40	0.04	A
ML	Male	23:21	-0.05	A	18:22	0.10	A
MM	Male	38:19	-0.33	L	46:28	-0.24	L
MP	Male	34:53	0.22	R	35:53	0.20	R
MT	Male	28:29	0.02	A	31:45	0.18	A
Population		507:608	0.09	A	588:658	0.06	A

L:R frequency of behaviors performed with left (L) and right (R) hands, HI handedness index, R right-hand preference, L left-hand preference, A ambipreference

^aHand preference determined with binomial z-score tests

primates (e.g., Marchant and McGrew 1996; Mittra et al. 1997; Motes Rodrigo et al. 2018; Sfar et al. 2014).

The absence of preferential hand use at the population level in mantled howler monkeys may result from the fact that we based our study on behaviors that are not manipulatively complex and generally do not require visual guidance. Touching and scratching correspond to low-level tasks, as defined by Fagot and Vauclair (1991), which are loosely regulated, familiar, practiced, and cognitively undemanding behaviors. In contrast to more demanding high-level tasks, low-level tasks are not expected to elicit preferential hand use (Fagot and Vauclair 1991), a prediction that is supported by evidence of ambilaterality in self-directed behaviors across primates (McGrew and Marchant 1998). For instance, squirrel monkeys (*Saimiri sciureus*) are ambilateral when touching their face or scratching their own body (Aruguete et al. 1992) but display hand preferences at the population level in manipulative tasks associated with picking up food (e.g., King and Landau 1993; Laska 1996).

However, red howler monkeys are ambilateral in diverse reaching-for-food tasks (Sfar et al. 2014). This lack of hand preference at the population level may be explained by the fact that howler monkeys do not execute manual actions that demand high precision (Milton 1980). Therefore, ambilaterality in howler monkeys may result from behavioral and morphological traits that are independent of task complexity. First, howler monkeys typically consume whole plant parts that they pick up from trees directly with their mouths. Likewise, howler monkeys eat fruits without any processing or individual selection (Milton 1980). They also exchange social interactions at very low rates and grooming, which requires high-level hand precision and visual attention, is rare (e.g., Ho et al. 2014). Additionally, howler monkeys do not use tools (Prieur et al. 2019), which require some level of hand dexterity for their manipulation (van Schaik et al. 1999). Thus, food processing and manipulation during socialization, which are two behavioral contexts that associate with preferential hand use in other primate species (Byrne and Byrne 1991; Marchant and McGrew 1996; McGrew and Marchant 1998), are likely weak selective pressures for preferential hand use in howler monkeys. Second, although howler monkeys are arboreal quadrupeds, a locomotion mode that may have favored the evolution of manual laterality (MacNeilage et al. 1987), they also have a prehensile tail. Howler monkeys use their tail for support during feeding and locomotion (Lawler and Stamps 2002), which may have decreased the likelihood of evolving laterality for support vs. manipulation (MacNeilage et al. 1987). The paucity of studies on laterality conducted with animals with prehensile tails limits the testing of this hypothesis, but it is worth noting that Geoffroy's spider monkeys (*Ateles geoffroyi*), another ateline species, similarly lack population-level preferential hand use (Motes Rodrigo et al. 2018).

Given the above, the types of manipulative actions that we studied should be little influenced by positional effects. Yet, as posture unavoidably determines which limbs are available for manipulation (McGrew and Marchant 1998), future research on howler monkey preferential hand use should account for positional behavior, with particular attention to hand preference while using the tail. Ontogenetic effects (Hopkins 1994; Prieur et al. 2019; Westergaard and Suomi 1993) should also not account for the observed patterns, as all subjects were fully grown adults belonging to the same population. However, as some females were observed in different reproductive states (e.g., gestating and lactating), a factor that could affect laterality either through hormonal modulation (Westergaard et al. 2000) or via postural constraints (Tomaszycki et al. 1998), variation in preferential hand use through the reproductive cycle of females, which could not be assessed here due to small sample size, remains to be determined. For now, our study contributes evidence of individual hand preferences but lack of population-level preferential hand use in mantled howler monkeys.

Acknowledgements We thank D. Canales Espinosa, Laura Johnson, and Jamie Whewell for their support during fieldwork and Ing. J. L. Ponce Puente for allowing the work at La Flor de Catemaco S.A. We thank two anonymous reviewers for very helpful comments and suggestions that substantially improved the manuscript. The study was financed by Consejo Nacional de Ciencia y Tecnología (CONACyT grant 1147976), Posgrado en Neuroetología, Instituto de Neuroetología (Universidad Veracruzana), and The Leakey Foundation. We complied with the ethical standards in the treatment of primates as described in the guidelines of the Primate Society of Japan and followed the Mexican Law (permit SGPA/DGVS/04015/21 from Secretaría de Medio Ambiente y Recursos Naturales). A. Rangel Negrín and P.A.D. Dias thank Mariana and Fernando for continued inspiration to understand primate behavior.

Data availability Analyzed data are included in the manuscript.

References

- Altmann J (1974) Observational study of behavior: sampling methods. *Behaviour* 49:227–266. <https://doi.org/10.1163/156853974x00534>
- Aruguete MS, Ely EA, King JE (1992) Laterality in spontaneous motor activity of chimpanzees and squirrel monkeys. *Am J Primatol* 27:177–188. <https://doi.org/10.1002/ajp.1350270303>
- Bisazza A, Pignatti R, Vallortigara G (1997) Detour tests reveal task- and stimulus-specific behavioural lateralization in mosquitofish (*Gambusia holbrooki*). *Behav Brain Res* 89:237–242. [https://doi.org/10.1016/S0166-4328\(97\)00061-2](https://doi.org/10.1016/S0166-4328(97)00061-2)
- Byrne RW, Byrne JM (1991) Hand preferences in the skilled gathering tasks of mountain gorillas (*Gorilla g. beringei*). *Cortex* 27:521–546. [https://doi.org/10.1016/S0010-9452\(13\)80003-2](https://doi.org/10.1016/S0010-9452(13)80003-2)
- Coller M, Segarra MD, Sabater-Pi J (1995) Manual laterality in chimpanzees (*Pan troglodytes*) in complex tasks. *J Comp Psychol* 109:298–307. <https://doi.org/10.1037/0735-7036.109.3.298>
- Cooper DL (2006) Broca's arrow: Evolution, prediction, and language in the brain. *Anat Rec* 289B:9–24. <https://doi.org/10.1002/ar.b.20088>

- Crockett CM, Eisenberg JF (1987) Howlers: Variations in group size and demography. In: Smuts BB, Cheney DL, Seyfarth RM, Wrangham RW, Struhsaker TT (eds) Primate societies. The University of Chicago Press, Chicago, pp 54–68
- de Andrade AC, de Sousa AB (2018) Hand preferences and differences in extractive foraging in seven capuchin monkey species. *Am J Primatol* 80:e22901. <https://doi.org/10.1002/ajp.22901>
- Dias PAD, Coyohua-Fuentes A, Canales-Espinosa D, Rangel-Negrín A (2023) Demography and life-history parameters of mantled howler monkeys at La Flor de Catemaco: 20 years post-translocation. *Primates* 64:143–152. <https://doi.org/10.1007/s10329-022-01030-z>
- Dutta A, Dasgupta D, Banerjee A, Hasnain SA, Sen D, Kuleri MS, Bhattacharjee P, Paul M (2024) Left or right: Handedness in free-ranging Hanuman langurs, *Semnopithecus entellus*, residing in an urban ecosystem. *Anim Behav* 210:409–418. <https://doi.org/10.1016/j.anbehav.2024.01.017>
- Ehret G (1987) Left hemisphere advantage in the mouse brain for recognizing ultrasonic communication calls. *Nature* 325:249–251. <https://doi.org/10.1038/325249a0>
- Fagot J, Vauclair J (1991) Manual laterality in nonhuman primates: a distinction between handedness and manual specialization. *Psychol Bull* 109:76–89. <https://doi.org/10.1037/0033-2909.109.1.76>
- Fitch WT, Braccini SN (2013) Primate laterality and the biology and evolution of human handedness: a review and synthesis. *Ann N Y Acad Sci* 1288:70–85. <https://doi.org/10.1111/nyas.12071>
- Ho L, Cortés-Ortiz L, Dias PAD, Canales-Espinosa D, Kitchen DM, Bergman TJ (2014) Effect of ancestry on behavioral variation in two species of howler monkeys (*Alouatta pigra* and *A. palliata*) and their hybrids. *Am J Primatol* 76:855–867. <https://doi.org/10.1002/ajp.22273>
- Hopkins WD (1994) Hand preferences for bimanual feeding in 140 captive chimpanzees (*Pan troglodytes*): Rearing and ontogenetic determinants. *Dev Psychol* 27:395–407. <https://doi.org/10.1002/dev.420270607>
- Hopkins WD (2013) Independence of data points in the measurement of hand preferences in primates: statistical problem or urban myth? *Am J Biol Anthropol* 151:151–157. <https://doi.org/10.1002/ajpa.22248>
- Hopkins WD, de Waal FBM (1995) Behavioral laterality in captive bonobos (*Pan paniscus*): Replication and extension. *Int J Primatol* 16:261–276. <https://doi.org/10.1007/BF02735481>
- Hopkins WD, Bennett AJ, Bales SL, Lee J, Ward JP (1993) Behavioral laterality in captive bonobos (*Pan paniscus*). *J Comp Psychol* 107:403–410. <https://doi.org/10.1037/0735-7036.107.4.403>
- Hopkins WD, Wesley MJ, Izard MK, Hook M, Schapiro SJ (2004) Chimpanzees (*Pan troglodytes*) are predominantly right-handed: replication in three populations of apes. *Behav Neurosci* 118:659–663. <https://doi.org/10.1037/0735-7044.118.3.659>
- Hoso M, Asami T, Hori M (2007) Right-handed snakes: convergent evolution of asymmetry for functional specialization. *Biol Lett* 3:169–173. <https://doi.org/10.1098/rsbl.2006.0600>
- Jones CB, Van Cantfort TE (2007) Multimodal communication by male mantled howler monkeys (*Alouatta palliata*) in sexual contexts: a descriptive analysis. *Folia Primatol* 78:166–185. <https://doi.org/10.1159/000099138>
- King JE, Landau VI (1993) Manual preference in varieties of reaching in squirrel monkeys. In: Ward JP, Hopkins WD (eds) Primate laterality: Current behavioral evidence of primate asymmetries, 1st edn. Springer, New York, pp 107–124
- Laska M (1996) A study of correlates of hand preferences in squirrel monkeys (*Saimiri sciureus*). *Primates* 37:457–465. <https://doi.org/10.1007/BF02381379>
- Lawler RR, Stamps C (2002) The relationship between tail use and positional behavior in *Alouatta palliata*. *Primates* 43:147–152. <https://doi.org/10.1007/BF02629675>
- Lonsdorf EV, Hopkins WD (2005) Wild chimpanzees show population-level handedness for tool use. *PNAS* 102:12634–12638. <https://doi.org/10.1073/pnas.0505806102>
- MacNeilage PF (1991) The “postural origins” theory of primate neurobiological asymmetries. In: Krasnegor NA, Rumbaugh DM, Schiefelbusch RL, Studdert-Kennedy M (eds) Biological and behavioral determinants of language development, 1st edn. Psychology Press, New York, pp 165–188
- MacNeilage PF, Studdert-Kennedy MG, Lindblom B (1987) Primate handedness reconsidered. *Behav Brain Sci* 10:247–263. <https://doi.org/10.1017/S0140525X00047695>
- Marchant LF, McGrew WC (1996) Laterality of limb function in wild chimpanzees of Gombe National Park: comprehensive study of spontaneous activities. *J Hum Evol* 30:427–443. <https://doi.org/10.1006/jhev.1996.0036>
- McGrew WC, Marchant LF (1998) On the other hand: current issues in and meta-analysis of the behavioral laterality of hand function in nonhuman primates. *Am J Biol Anthropol* 104:201–232. [https://doi.org/10.1002/\(SICI\)1096-8644\(1997\)25+<3c201::AID-AJPA8%3e3.0.CO;2-6](https://doi.org/10.1002/(SICI)1096-8644(1997)25+<3c201::AID-AJPA8%3e3.0.CO;2-6)
- Milliken GW, Stafford DK, Dodson DL, Pinger CD, Ward JP (1991) Analyses of feeding lateralization in the small-eared bushbaby (*Otolemur garnettii*): a comparison with the ring-tailed lemur (*Lemur catta*). *J Comp Psychol* 105:274–285. <https://doi.org/10.1037/0735-7036.105.3.274>
- Milton K (1980) The foraging strategy of howler monkeys. Columbia University Press, New York
- Mittra ES, Fuentes A, McGrew WC (1997) Lack of hand preference in wild Hanuman langurs (*Presbytis entellus*). *Am J Phys Anthropol* 103:455–461. [https://doi.org/10.1002/\(sici\)1096-8644\(199708\)103:4%3c455::aid-ajpa3%3e3.3.co;2-y](https://doi.org/10.1002/(sici)1096-8644(199708)103:4%3c455::aid-ajpa3%3e3.3.co;2-y)
- Motes Rodrigo A, Ramírez Torres CE, Hernández Salazar LT, Laska M (2018) Hand preferences in two unimanual and two bimanual coordinated tasks in the black-handed spider monkey (*Ateles geoffroyi*). *J Comp Psychol* 132:220–229. <https://doi.org/10.1037/com0000110>
- Prieur J, Lemasson A, Barbu S, Blois-Heulin C (2019) History, development and current advances concerning the evolutionary roots of human right-handedness and language: Brain lateralisation and manual laterality in non-human primates. *Ethology* 125:1–28. <https://doi.org/10.1111/eth.12827>
- Rogers LJ, Kaplan G (1996) Hand preferences and other lateral biases in rehabilitated orang-utans, *Pongo pygmaeus pygmaeus*. *Anim Behav* 51:13–25. <https://doi.org/10.1006/anbe.1996.0002>
- Sfar N, Mangalam M, Kaumanns W, Singh M (2014) A comparative assessment of hand preference in captive red howler monkeys, *Alouatta seniculus* and yellow-breasted capuchin monkeys, *Sapajus xanthosternos* *Plos ONE* 9:e107838. <https://doi.org/10.1371/journal.pone.0107838>
- Tomaszycki M, Cline C, Griffin B, Maestripieri D, Hopkins WD (1998) Maternal cradling and infant nipple preference in rhesus monkeys (*Macaca mulatta*). *Dev Psychobiol* 32:305–312. [https://doi.org/10.1002/\(SICI\)1098-2302\(199805\)32:4%3c305::AID-DEV5%3e3.0.CO;2-R](https://doi.org/10.1002/(SICI)1098-2302(199805)32:4%3c305::AID-DEV5%3e3.0.CO;2-R)
- van Schaik CP, Deaner RO, Merrill MY (1999) The conditions for tool use in primates: Implications for the evolution of material culture. *J Hum Evol* 36:719–741. <https://doi.org/10.1006/jhev.1999.0304>
- Vauclair J, Meguerditchian A, Hopkins WD (2005) Hand preferences for unimanual and coordinated bimanual tasks in baboons (*Papio anubis*). *Cogn Brain Res* 25:210–216. <https://doi.org/10.1016/j.cogbrainres.2005.05.012>
- Westergaard GC, Suomi SJ (1993) Hand preference in capuchin monkeys varies with age. *Primates* 34:295–299. <https://doi.org/10.1007/BF02382624>

- Westergaard GC, Kuhn HE, Suomi SJ (1998) Bipedal posture and hand preference in humans and other primates. *J Comp Psychol* 112:55–64. <https://doi.org/10.1037/0735-7036.112.1.55>
- Westergaard GC, Lussier ID, Suomi SJ (2000) Hormonal correlates of hand preference in free-ranging primates. *Neuropsychopharmacology* 23:502–507. [https://doi.org/10.1016/S0893-133X\(00\)00141-X](https://doi.org/10.1016/S0893-133X(00)00141-X)

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.