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Reaction to Snakes in Wild Moor Macaques (*Macaca maura*)

Clara Hernández Tienda[1] · Víctor Beltrán Francés[1] · Bonaventura Majolo[2] · Teresa Romero[3] · Risma Illa Maulany[4] · Putu Oka Ngakan[4] · Federica Amici[5,6]

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Abstract
Snake predation is considered an important evolutionary force for primates. Yet, very few studies have documented encounters between primates and snakes in the wild. Here, we provide a preliminary account of how wild moor macaques (*Macaca maura*) respond to seven species of real and model snakes. Snakes could be local and dangerous to the macaques (i.e., venomous or constricting), local and nondangerous, and novel and dangerous. Macaques reacted most strongly to constrictors (i.e., pythons), exploring them and producing alarm calls, and partially to vipers (both local and novel), exploring them but producing no alarm calls. However, they did not react to other dangerous (i.e., king cobra) or nondangerous species. Our results suggest that moor macaques discriminate local dangerous snakes from nondangerous ones, and may use specific cues (e.g., triangular head shape) to generalize their previous experience with vipers to novel species.

Keywords Snakes · Pythons · Vipers

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✉ Clara Hernández Tienda
claraclaraht@gmail.com

✉ Federica Amici
amici@eva.mpg.de

1 Fundació UdG: Innovació i Formació, Universitat de Girona, Girona, Spain

2 School of Psychology, University of Lincoln, Lincoln, UK

3 School of Life Sciences, University of Lincoln, Lincoln, UK

4 Forestry Department, Hasanuddin University, Makassar, Sulawesi, Indonesia

5 Department of Human Behavior, Research Group Primate Behavioral Ecology, Ecology and Culture, Max-Planck Institute for Evolutionary Anthropology, Leipzig, Germany

6 Behavioral Ecology Research Group, Institute of Biology, Faculty of Life Science, University of Leipzig, Leipzig, Germany

Predation is an important evolutionary force. Snakes are one of the most common primate predators and might have contributed to the evolution of primate visual and perceptual skills, as rapid predator detection increases survival (Isbell, 2009; *cf.* Wheeler *et al.*, 2011). When they detect a snake, primates often react by producing alarm calls that might attract and/or inform other group members about its presence, and/or by mobbing it (i.e., gathering around it in a state of arousal and harassing it; e.g., Crockford *et al.*, 2012). However, very few studies have documented encounters between primates and snakes in the wild (e.g., Ramakrishnan *et al.*, 2005).

Here, we provide a preliminary account of how moor macaques (*Macaca maura*) respond to several different species of real and model snakes. We tested 1) whether macaques discriminate between snakes that are dangerous (i.e., venomous or constricting) and nondangerous to the macaques, and 2) how macaques react to novel snake species (i.e., species that do not live within the geographic range of moor macaques). We studied a group of semihabituated wild moor macaques, including 56 individuals and located in a secondary forest area surrounded by the facilities of Hasanuddin University (5°00′S 119°46′E), crop fields, and Bengo village (Maros Regency) in Sulawesi, Indonesia.

We conducted the study between January 2019 and March 2020, using two different approaches. First, we monitored macaque behavior during natural encounters with real snakes. Whenever we noted that the macaques detected (i.e., were in visual contact with) a real snake, we identified the species and recorded whether macaques 1) produced alarm calls; 2) reacted to the alarm calls of other group members by approaching the snake; 3) explored the snake visually, tactually, or olfactorily; 4) mobbed it; or 5) avoided it by abruptly changing direction. We also recorded the approximate minimum distance between the monkeys and the snake.

Second, we conducted field experiments (see Ramakrishnan *et al.*, 2005 for similar methods). We prepared six different model snakes, painting rubber snakes and shaping their posture with internal wire, so that the models looked like the living snakes in size, color, and posture. Model snakes belonged to three different categories (de Lang & Vogel, 2005): 1) local and dangerous, 2) local and nondangerous, and 3) novel and dangerous. We placed snake models in a natural position (e.g., coiled on a rock) when the monkeys were absent, in areas often used by macaques and with good visibility. We recorded macaque–snake encounters from different angles with two Bushnell camera traps and a Lumix DMC-TZ100 videocamera held by the first author. We collected the same data as for encounters between macaques and real snakes. We administered eight trials (i.e., one for each of the six model snakes, except for the Bornean keeled green pit viper [*Tropidolaemus subannulatus*] and the banded pit viper [*Trimereserus fasciatus*], which we used twice). We randomized the presentation order, with the rate of trials being lower than the natural encounter rate to avoid habituation (i.e., twice a month; C. H. Tienda, V. B. Francés, and P. O. Ngakan, *pers. obs.*). If macaques discriminate between local dangerous and local nondangerous snakes, they should produce and react to alarm calls and mob or avoid dangerous snakes more frequently than nondangerous snakes. In contrast, macaques should explore nondangerous snakes for longer and from a closer distance than dangerous snakes. If macaques use visual cues (e.g., head shape) to generalize their previous experience with dangerous species to novel species, they should react to novel dangerous species more similarly to local dangerous than to nondangerous snakes, by more frequently producing and reacting to alarm calls and mobbing or avoiding novel dangerous snakes than local nondangerous species. If macaques acquire fear of snakes socially through species-specific experience (Isbell, 2009), however, they should react to novel dangerous species more similarly to local nondangerous than dangerous snakes, by less frequently producing and reacting to alarm calls, mobbing or avoiding novel dangerous snakes than local dangerous species.

We recorded three natural encounters with real snakes, all with dangerous species, including one encounter with a venomous species (Bornean keeled green pit viper), and two with a constrictor (reticulated python, *Python reticulatus*; Table I). The macaques detecting a snake did not mob or avoid it in these encounters, or in any of the eight trials with model snakes. However, when they detected a real python (local dangerous, N = 2), macaques produced alarm calls, and the rest of the group gradually approached and produced alarm calls. Macaques explored the snake during all encounters with pythons (real, local and dangerous, N = 2) and vipers (real, local, and dangerous, N = 1; model, local and dangerous, N = 2; model, novel and dangerous, N = 2). Exploration was mostly visual or olfactory, with one juvenile touching a novel model viper once. Macaques may explore pythons and vipers to obtain essential information (e.g., about snake size or reactivity). In contrast, the distance between monkeys and snakes followed no clear pattern, varying in a similar way across all the three categories tested (i.e., local and dangerous: 0.05–2.00 m, local and nondangerous: 0.60–2.50 m, and novel and dangerous: 0–1.00 m; Table I).

Alarm calls occurred only during python encounters, as in other members of the *Macaca* genus (Ramakrishnan *et al*., 2005). Other local and highly venomous snakes (Bornean keeled green pit viper and king cobra, *Ophiophagus hannah*) elicited no alarm calls, in contrast to findings for bonnet macaques, which alarm call when they detect king cobras (Ramakrishnan *et al*., 2005). Although it is possible that no responses during natural encounters were not detected, and thus undercounted, these limited observations suggest that moor macaques react most strongly to constrictors (i.e., pythons), partially to vipers (exploring them, but producing no alarm calls), and not to other dangerous (i.e., king cobra) or nondangerous species. Although there are several reports of primates (including macaques) being killed by venomous snakes, it is likely that pythons constitute a much higher predation pressure on macaques than venomous species do (see Isbell, 2009; Wheeler *et al*., 2011). If possible, longer-term studies should monitor primate mortality due to snakes to assess the effective danger that different snakes pose to primates. Finally, macaques reacted similarly to novel and local vipers (exploring them but producing no alarm calls), while they showed no visible reaction to the other novel venomous snake model (blue krait, *Bungrus candidus*). This suggests that macaques may use specific cues (e.g., triangular head shape) to generalize their previous experience with vipers to novel species. While more studies are needed to confirm these preliminary observations, it appears that moor macaques may reliably discriminate at least pythons and vipers from other snakes.

Ethical Note

The study was merely observational. Researchers never fed or directly interacted with the moneys, and always maintained a distance of ≥10 m from the monkeys. There was never any form of physical contact with the monkeys. The procedures were approved

Table I Summary of observations we made between January 2019 and March 2020 of a group of moor macaques (*Macaca maura*) in Bengo (Sulawesi, Indonesia)

Snake				Macaque reaction					
Real/model	Local/novel	Dangerous to macaques	Species	Alarm calls		Explore	Mob	Avoid	Minimum distance (m)
				Produced	Group members reacted				
Real	Local	Venomous	Bornean keeled green pit viper (*Tropidolaemus subannulatus*)	✗	—	Visual	✗	✗	0.05
		Constricting	Reticulated python (*Python reticulatus*)	✓	✓	Visual	✗	✗	<0.50
				✓	✓	Visual	✗	✗	2.00
Model	Local	Venomous	Bornean keeled green pit viper (*Tropidolaemus subannulatus*)	✗	—	Visual, olfactory	✗	✗	0.50
				✗	—	Visual, olfactory	✗	✗	0.05
		Venomous	King cobra (*Ophiophagus hannah*)	✗	—	✗	✗	✗	2.00
Model	Local	No	Sulawesi paradise tree snake (*Chrysopelea paradisi celebensis*)	✗	—	✗	✗	✗	0.60
		No	Sulawesi rat snake (*Elaphe erythrura celebensis*)	✗	—	✗	✗	✗	2.50
Model	Novel	Venomous	Blue krait (*Bungarus candidus*)	✗	—	✗	✗	✗	1.00
		Venomous	Banded pit viper (*Trimeresurus fasciatus*)	✗	—	Visual, olfactory	✗	✗	0.05
				✗	—	Visual, tactile	✗	✗	0

We coded alarm call as a short call with a tonal unit and then a harsh unit, sounding like a bark. We coded visual exploration as individuals looking attentively at the snake by directing their face and gaze to it for several seconds after detection. We coded olfactory exploration as individuals bringing their nose within 5 cm of the snake, in its direction. We coded tactile exploration as individuals touching the snake while inspecting it visually. We coded mobbing as individuals cooperatively attacking or harassing the snake by the Indonesian Foreign Research Permit Division, Ministry of Research and Technology/National Research and Innovation Agency, and by the Faculty of Forestry of the Hasanuddin University. This study adhered to the American Society of Primatology Principles for the Ethical Treatment of Nonhuman Primates.

Data Availability Data are provided in the text.

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Author contributions FA conceived and designed the experiments, and prepared the stimuli, with feedback from BM, TR, RIM and PON. CHT and VBF collected the data. CHT analyzed the data, with input from FA. CHT and FA wrote the manuscript, with substantial help from all the other co-authors.

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