Acoustical and morphological comparisons between albino and normally-pigmented Jamaican fruit bats (*Artibeus jamaicensis*)

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Abstract.–Although rare, hypopigmentary disorders have been observed in many vertebrate species. These disorders include albinism, leucism, and piebaldism, and can be differentiated based on the pattern and degree of lack of pigmentation. For many species, these disorders persist in nature, suggesting that affected animals can survive and potentially reproduce. Here we report a case of albinism in a Jamaican fruit bat (*Artibeus jamaicensis*) captured from a cave dwelling in Cuba. In addition to describing this albino individual's morphological characteristics, we recorded acoustical parameters of echolocation calls during foraging in a flight chamber. We found that the albino individual emits high-frequency multi-harmonic calls with short durations, which are characteristic of this species and other phyllostomid bats. We discuss potential acoustical adaptations in albino bats that could facilitate their survival and suggest future approaches to studying these unique animals.

Hypopigmentary disorders are rare phenomena that occur in many vertebrate species, including mammals, amphibians, reptiles, birds, and fish. Albinism is classified as an ocular and integumentary coloration condition and features total absence of pigmentation of the eyes, skin, hair, and feathers (van Grouw 2006, 2013; Abreu et al. 2013; Lucati and López-Baucells 2016). In mammals, the condition results from inherited mutations in the gene encoding tyrosinase, the rate-limiting enzyme involved in one of the first steps of melanin production (Oetting and King 1999; Yamaguchi et al. 2007). Leucism is characterized by total absence of pigmentation of the skin, hair, and feathers, but normal coloration of the eyes (van Grouw 2006, 2013; Abreu et al. 2013; Lucati and López-Baucells 2016). Piebaldism features localized absence or reduction of pigment in certain areas of the skin, hair, or feathers; animals with this condition have one or more white patches on the body (Abreu et al. 2013; Lucati and López-Baucells 2016). Leucism and piebaldism are caused by disruption of pigment deposition, and are sometimes incorrectly referred to as "partial albinism" (van Grouw 2006, 2013; Abreu et al. 2013; Lucati and López-Baucells 2016).

Despite being rare phenomena, albinism, leucism, and piebaldism have been observed in bats. In their review of chromatic disorders in bats, Lucati and López-Baucells (2016) found that some form of pigmentary disorder has been reported for 609 bats belonging to 115 species worldwide. Some recent reports include chromatic disorders in the following species: *Artibeus lituratus* (Zalapa et al. 2016), *Artibeus planirostris* (Chacón et al. 2015), *Anoura geoffroyi* (Hargreaves 2015), *Glossophaga soricina* (Zalapa et al. 2016), *Molossus sinaloae* (Zalapa et al. 2016), *Nyctinomops femorosaccus* (Zalapa et al. 2016), *Sturnira lilium* (Zalapa et al. 2016), *Tadarida brasiliensis* (Romano et al. 2015), and *Taphozous* sp. (Dhanya et al. 2015).

Phyllostomidae constitutes one of the most diverse bat families in the Neotropics (Taboada 1979; Koopman 1984) and the Jamaican fruit bat (*Artibeus jamaicensis*) is one of the most widely distributed species (Morrison 1978; Flores-Martínez et al. 2000). Here we report a case of albinism in a male *A. jamaicensis*. We describe this albino individual's morphological characteristics and acoustical parameters of echolocation during foraging in captivity. To the best of our knowledge, we make the first direct comparisons of this albino *A. jamaicensis* with other normally-pigmented individuals of this species.

Materials and Methods

Study area

We conducted this study between 7 February and 16 March 2014. On 7 February 2014 at 17:30 hours, we captured an albino male individual of *A. jamaicensis* while roosting at dusk from a cave dwelling. The cave is located outside a small town named El Mudo (22°56'00.0" N, 81°55'00.0" W) approximately 50 km east of Havana, Cuba. The climate in this area features warm temperatures, high humidity, and frequent rainfalls in the summer months. The dominant vegetation is

FIG. 1. Ventral view of a male *Artibeus jamaicensis* with albinism (MFP 16.000187). The albino individual shows several prominent characteristics, including the presence of white pelage, pinkish-red eyes, semitransparent flight membranes, distinct arteries in the wings, and pronounced scrotal testes.

tropical deciduous forest, including Yagruam (*Cecropia peltata*), Ceiba (*Ceiba pentandra*), and various trees of the genus *Acacia*. The cave has a single entrance and consists of three large rooms, in addition to many voids and fissures of various sizes. The cave is approximately 150 meters deep and the height ranges from 20 to 35 meters. Based on a visual estimate, the cave houses approximately 300 individuals of the species *A. jamaicensis*, which are distributed between 75 and 100 m from the entrance of the cave in groups of 5–20 individuals. The albino male individual was located at approximately 100 m from the entrance of the cave, roosting with a group of seven other normally-pigmented individuals.

Experimental design

Following capture, the albino male's forearm length was measured using Vernier calipers (0.1 mm division) and the individual was placed in a stainless-steel wire mesh holding cage (41 × 22 × 33 cm). Temperature and humidity varied with ambient conditions and darkness was maintained at all times by placing a thick towel around the cage. Body mass was measured for the first 30 days in captivity using a Pesola spring scale (60 g capacity, 0.5 g division; Pesola AG, Baar, Switzerland). The bat was given *ad libitum* access to water and fed twice daily at the onset of dawn and dusk with an assortment of fruit (papaya, guava, and banana) sufficient to maintain the individual's weight. At 30 days after capture, the albino individual was transferred to a large chamber (4.5 × 1.5 × 0.90 m) and housed with four normally-pigmented conspecific males whose forearm length and body mass were measured at the time of entry into this chamber. Bats were housed in the chamber for seven days prior to recording of echolocation calls, after which the four normally-pigmented males were released from captivity. The albino bat was returned to the stainless-steel wire mesh holding cage and housed in captivity for another 10 months. The bat was preserved as a specimen in 70% ethanol solution following natural death, and deposited in the Felipe Poey Museum of Natural History at Havana University (specimen code MFP 16.000187).

We recorded the echolocation calls of a single male albino individual and 4 male normally-pigmented individuals of *A. jamaicensis*. Recordings were conducted as previously published (Macías and Mora 2006, Mora

and Macías 2011). In brief, acoustic recordings during foraging were obtained from bats flying in a flight chamber (4.5 × 1.5 × 0.90 m). The recording system and several pieces of fruit were placed at one end of the chamber. Bats were released into the chamber at the opposite end, flew in a straight trajectory toward the microphone, and landed on the food source. Echolocation calls were recorded using a CM16/CMPA ultrasound condenser microphone (Avisoft Bioacoustics, Glienicke, Germany). Calls were digitized using the accompanying Avisoft Recorder USGH software. Signals were amplified using an Avisoft UltraSoundGate 416Hnbm multichannel amplifier (Avisoft Bioacoustics, Glienicke, Germany). The gain was fixed to obtain an ideal signal to noise ratio and sampling frequency was set at 250 kHz with a 5 kHz high pass filter. Recordings were analyzed with Avisoft SASLab Pro 5.4.1 software (Avisoft Bioacoustics, Glienicke, Germany). Spectrograms were made of consecutive fast Fourier transforms (FFT) with a 98% overlap. Usually, a 256 point FFT was chosen to obtain ideal frequency (976 Hz) and temporal (1.02 ms) resolutions.

For all echolocation calls with a maximum intensity of more than 20 dB above the ambient noise level, we recorded the following acoustical parameters: (1) duration of the signal, the time between the start and the end of a pulse; (2) peak frequency, the frequency corresponding to the maximum intensity in the power spectrum; (3) minimum frequency and (4) maximum frequency, the lowest and highest values, respectively, of frequency measured 20 dB below maximum intensity in the power spectrum; (5) bandwidth, calculated as the difference between maximum and minimum frequencies. We also isolated the second, third, and fourth harmonics, which represent key events in the foraging process. For these harmonics, we measured all of the above parameters, as well as: (6) slope of frequency modulation, calculated as the difference between the initial and final frequency of the harmonic divided by the duration of the harmonic. We did not make statistical comparisons between albino and normally-pigmented bats, as recording multiple pulses from a single bat is a form of pseudo-replication (Hurlbert 1984). All procedures adhered to the guidelines for the care and use of wild mammals in research approved by the American Society of Mammalogists (Sikes et al. 2011) and the Canadian Council on Animal Care.
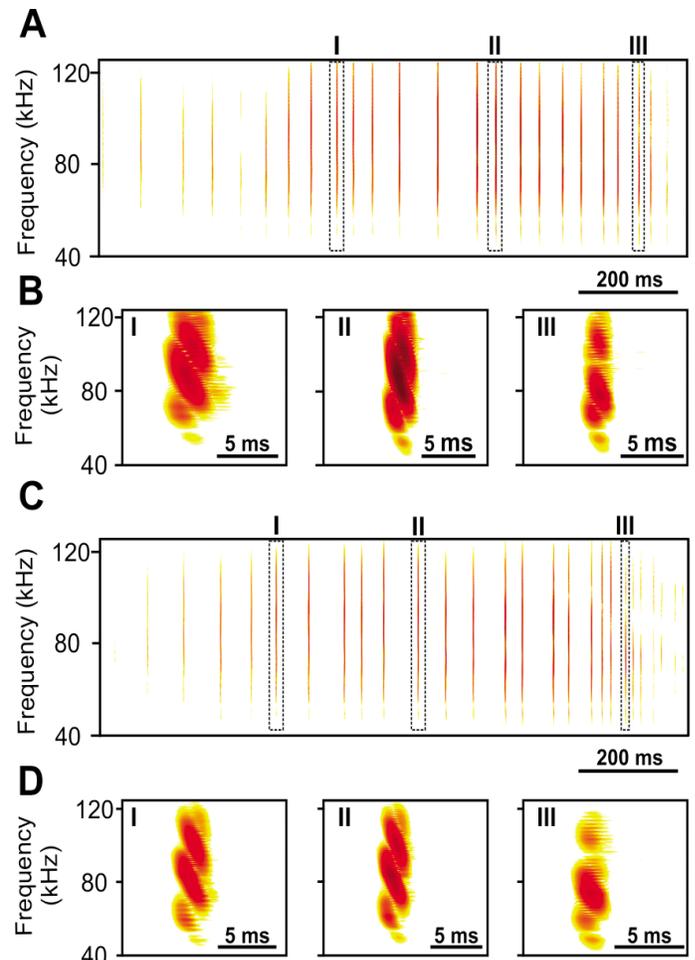

FIG. 2. Spectrograms recorded from echolocation calls of albino and normally-pigmented *Artibeus jamaicensis* during foraging. Latency between calls decreased as the albino (A) and normally-pigmented (C) bats approached the food source. Expanded spectrograms (I, II, and III) showed a decrease in call duration and frequency as the albino (B) and normally-pigmented (D) bats approached the food source.

RESULTS

Morphology of albino A. jamaicensis

The captured albino specimen was an adult male with forearm length of 52.3 mm and body mass of 35.1 ± 1.1 g. The albino individual showed white pelage over the entire body and the phalanges could be easily detected through the skin (Fig. 1). In some areas, such as the ventral surface of the body and the head, a dull yellow coloration was observed, presumably due to contact with pollen while foraging for fruit. The eyes of the albino individual were pinkish-red in color and the scrotal testes were pronounced. The flight membranes of the albino individual were semitransparent due to their thinness and several bright red arteries were visible.

TABLE 1. Mean values ± SD of the acoustical parameters measured from echolocation calls of *A. jamaicensis* albino and normally-pigmented bats during foraging. N = number of animals; n = number of individual pulses recorded; DUR = duration; PF = peak frequency; MINF = minimum frequency; MAXF = maximum frequency; BW = bandwidth; SFM = slope of frequency modulation; kHz = kilohertz; ms = millisecond; * = non-overlapping variances with normally-pigmented bats for that parameter.

Segment	Parameters	Albino Bat ($N = 1$)	Normally-Pigmented Bats ($N = 4$)
Entire Call	n	63	80
	DUR (ms)	2.13 ± 0.30	2.22 ± 0.35
	PF (kHz)	89.79 ± 4.03	83.67 ± 5.61
	MINF (kHz)	61.34 ± 1.02*	54.44 ± 2.28
	MAXF (kHz)	121.58 ± 2.77	118.60 ± 4.87
	BW (kHz)	60.21 ± 2.31	64.11 ± 5.36
Second Harmonic	n	58	77
	DUR (ms)	1.91 ± 0.30	1.89 ± 0.38
	PF (kHz)	69.43 ± 1.80	64.03 ± 7.06
	MINF (kHz)	53.34 ± 3.18	50.98 ± 2.96
	MAXF (kHz)	80.90 ± 1.54	77.58 ± 11.89
	BW (kHz)	27.50 ± 2.93	26.56 ± 11.38
	SFM (kHz/ms)	14.73 ± 2.28	14.14 ± 4.66
Third Harmonic	n	61	76
	DUR (ms)	1.92 ± 0.21	1.97 ± 0.30
	PF (kHz)	88.61 ± 2.44*	81.90 ± 2.98
	MINF (kHz)	72.14 ± 1.51	66.76 ± 4.66
	MAXF (kHz)	106.63 ± 2.03	100.38 ± 6.06
	BW (kHz)	34.45 ± 1.63	33.56 ± 10.07
	SFM (kHz/ms)	18.16 ± 1.88	17.41 ± 5.78
Fourth Harmonic	n	58	75
	DUR (ms)	1.78 ± 0.25	1.79 ± 0.25
	PF (kHz)	106.60 ± 1.91	102.00 ± 2.78
	MINF (kHz)	90.11 ± 1.52	87.04 ± 3.85
	MAXF (kHz)	123.52 ± 0.82*	118.95 ± 2.67
	BW (kHz)	33.39 ± 1.38	31.58 ± 2.44
	SFM (kHz/ms)	19.09 ± 2.59	18.05 ± 2.60

Consistent with the albino individual, normally-pigmented members of this species typically possess dense, soft pelage over the whole body and do not have a distinct tail. Four normally-pigmented males had forearm lengths of 51.6 ± 2.2 mm and body masses of 34.1 ± 3.4 g, indicating the albino individual was of normal size for this species. In contrast to the albino individual, normally-pigmented members of this species have dark brown eyes and grayish-brown fur with white tips on abdominal hairs giving them a "frosted" appearance. In normally pigmented individuals, the phalanges and testes are not very pronounced and require closer inspection to detect. No arteries are visible through the flight membranes of normally-pigmented individuals.

Echolocation calls during foraging

We recorded echolocation calls of five *A. jamaicensis* individuals, consisting of 63 pulses from the albino bat and 80 pulses from four normally-pigmented

bats. Echolocation calls emitted by *A. jamaicensis* were downward high-frequency modulated multi-harmonic calls of short duration (Fig. 2). Calls recorded from albino and normally-pigmented bats were very similar, emitting paired pulses with progressively shorter latency between pulses as the bat approached the food source (Figs. 2A, 2C). Moreover, echolocation calls decreased in duration and frequency as the bats approached the food source (Figs. 2B, 2D).

Acoustical parameters for the entire call, as well as the second, third, and fourth harmonics, are presented in Table 1. We noticed a general trend that the albino bat produced higher frequency calls than normally-pigmented bats, as observed in the peak frequency, minimum frequency, and maximum frequency for the entire call, as well as second, third, and fourth harmonics. However, in most cases, the variance among pulses was large, resulting in overlapping variances between the albino and normally-pigmented bats. Non-overlapping variances were observed for the minimum frequency of the entire call, the peak frequency of the third harmonic, and the maximum frequency of the fourth harmonic; this might be indicative of a meaningful effect whereby the albino bat emitted calls at higher frequencies for these parameters.

DISCUSSION

The Jamaican fruit bat (*A. jamaicensis*) is widely distributed in large populations throughout several countries in South and Central America (Ortega and Castro-Arellano 2001). Given that hypopigmentary disorders are rare phenomena in bats, only 12 previous cases have been reported for *A. jamaicensis* (Taboada 1979; Uieda 2000; Hernández-Mijangos 2009; García-Morales et al. 2010, 2012; Marín-Vásquez et al. 2010, 2013; Sánchez-Hernández et al. 2010, 2012). Of these 12 cases, Lucati and López-Baucells (2016) classified two as albinism (Taboada 1979; Uieda 2000), one as leucism (Marín-Vásquez et al. 2010), five as piebaldism (Hernández-Mijangos 2009; García-Morales et al. 2012; Sánchez-Hernández et al. 2012), one as hypomelanism (Sánchez-Hernández et al. 2010), and three as undetermined (García-Morales et al. 2010; Marín-Vásquez et al. 2013). Records of chromatic disorders in *A. jamaicensis* originated from four countries, including Cuba (Taboada 1979), Brazil (Uieda 2000), Colombia (Marín-Vásquez et al. 2010, 2013), and Mexico (Hernández-Mijangos 2009; García-Morales et

al. 2010, 2012; Sánchez-Hernández et al. 2010, 2012).

Despite two previous records of albinism in *A. jamaicensis*, this report is the first to describe the morphology of an albino *A. jamaicensis* and compare it to other normally-pigmented individuals of this species. Understanding the morphology of these bats could help guide future studies of physiology, which can be important for animal management and conservation (Faure et al. 2009). For example, albino bats offer unique insight into the locations of arteries in flight membranes, which could be used to guide sites of tissue biopsy (Faure et al. 2009; Ceballos-Vasquez et al. 2015; Pollock et al. 2016). Flight membrane biopsies near major blood vessels are recommended to obtain tissue samples for molecular analyses since the wounds heal faster (Pollock et al. 2016). Conversely, biopsies distant from major blood vessels are recommended for long-term identification of individual bats in the field since the wounds heal slower (Pollock et al. 2016).

All bats used in this study performed similar foraging behavior to that previously described for this species and other phyllostomid bats (Thies et al. 1998; Macías and Mora 2006; Macías et al. 2006; Brinkløv et al. 2009). Calls were of a similar structure to that previously shown for adult *A. jamaicensis* during echolocation (Carter et al. 2014); bats emit paired pulses with decreasing call duration and latency between calls during the approach towards the food source (Macías and Mora 2006). These calls were downward high-frequency modulated multi-harmonic calls of short duration. However, calls emitted in a flight chamber may not accurately represent calls emitted during foraging in the wild. Bats in confined spaces, such as flight chambers, emit calls of shorter duration, decreased intensity, and higher repetition rate compared to bats in their natural habitat (Surlykke and Moss 2000; Schnitzler and Kalko 2001; Surlykke et al. 2009; Brinkløv et al. 2010). Calls emitted in a flight chamber are also more variable than those made in the wild, likely contributing to the large within-individual variance observed in this study (Surlykke and Moss 2000; Surlykke et al. 2009). Despite this limitation, the flight chamber was required to prevent loss of the albino specimen during recording. Echolocation calls emitted by the albino individual were of nearly identical temporal pattern and underlying structure to those emitted by normally-pigmented bats of this species (Carter et al. 2014).

Although most bat species rely extensively on echolocation, they may also incorporate other sensory information, such as olfaction and vision, to navigate their environment, forage, and avoid danger (Thies et al. 1998; Heffner et al. 2001; Rydell and Eklöf 2003). This is especially true in fruit-eating bats, such as *A. jamaicensis*, which possess much larger olfactory receptor areas and retinal areas compared to insectivorous species, such as *Myotis lucifugus* (Bhatnagar 1975). Moreover, a lack of pigment in the eyes negatively affects vision in many mammalian species (Creel et al. 1990; Perez-Carpinell et al. 1992; Guillery 1996; Heiduschka and Schraermeyer 2008). Albino bats may rely on certain adaptations to compensate for reduced visual acuity and other disadvantages associated with albinism, such as a greater risk of predation caused by the lack of camouflage with its surroundings (Uieda 2000).

Despite being rare phenomena, newly discovered bats with chromatic disorders are being reported at increasing rates in scientific publications (Lucati and López-Baucells 2016). Given that at least 40% of records misclassify the type of chromatic disorder (van Grouw 2006, 2013; Abreu et al. 2013; Lucati and López-Baucells 2016), we suggest following the recommendations of Lucati and López-Baucells (2016) to distinguish albinism, leucism, piebaldism, and other hypopigmentary disorders involving melanin in bats. Given that approximately 42% of records do not specify the location of discovery (Lucati and López-Baucells 2016), it is also important to provide complete information pertaining to the environment in which the bat was first sighted. Uieda (2000) suggested that sheltered roosts favor survival of albino bats by offering protection against sunlight, water loss, and predation. Indeed, 297 of 354 albino bats (84%) for which a location was reported were discovered in closed roost sites, such as caves, buildings, and mines (Lucati and López-Baucells 2016). We encourage researchers to not only report new cases of albinism, but to also investigate the potential adaptations that may help overcome disadvantages caused by abnormal pigmentation.

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