Biomechanics of the peafowl's crest reveals frequencies tuned to social displays

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Movie S1. Dynamic peacock courtship displays and robotic experiments. When peacocks perform the train-rattling display, peahens are typically within 0.5-2 m away from the center of the bowl-shaped train as it vibrates. The position of the peahen relative to the wing shaking display is more variable but is often within 2 m. The peacock's wing feather tips trace a circular orbit while the wingplane remains in the same orientation during the wing-shaking display. This example clip is slowed down by a factor of 10 times. We used a wing-shaking robot to study the effect of wing-shaking on the nearby crest feathers, also slowed down by 10 times. The last clip in this video shows the response of a peafowl crest impacted by an air vortex that has been rendered visible using special effects smoke and slowed down by 20 times.

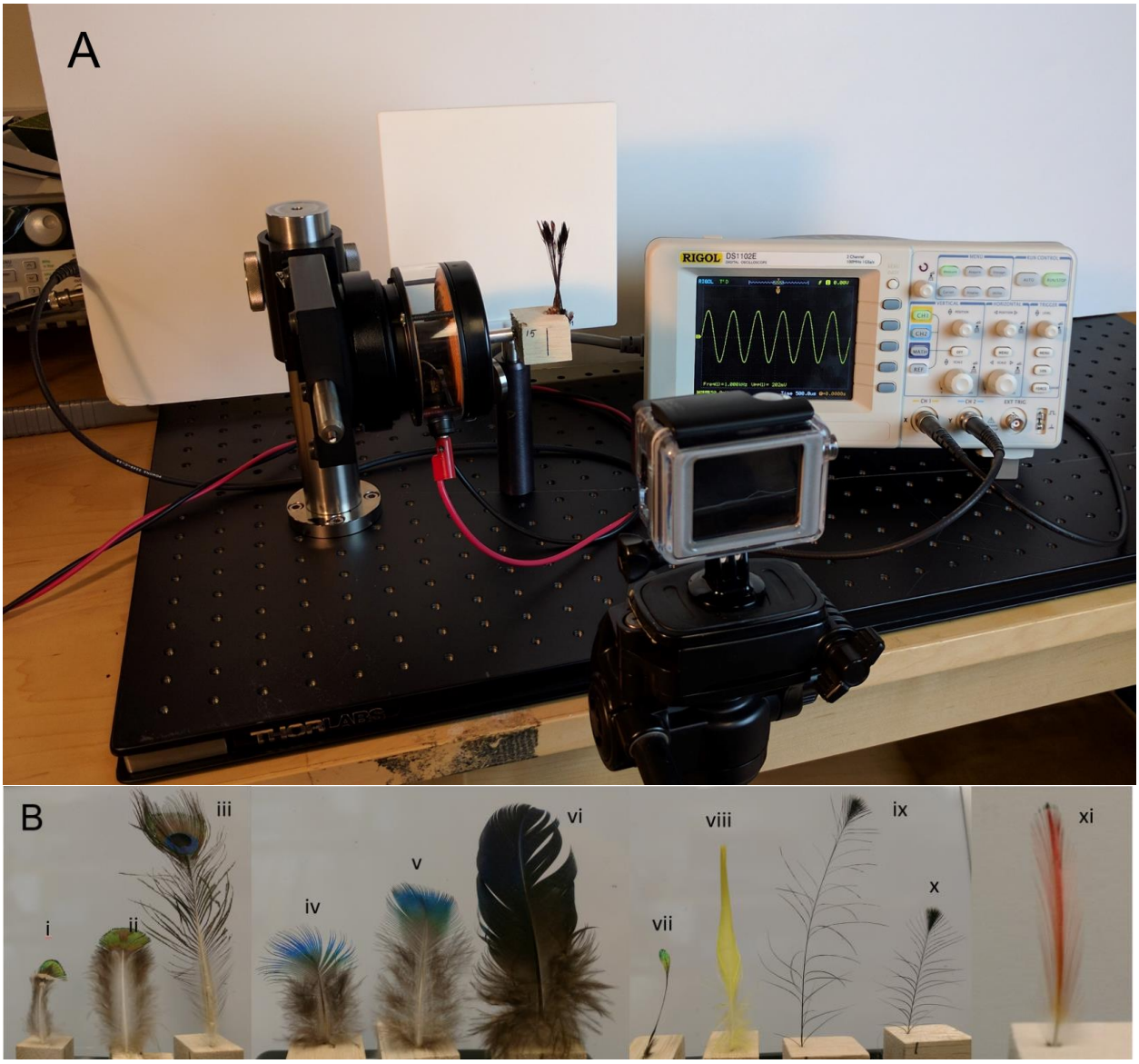

Fig. S1. (A) Apparatus for measuring the vibrational response of peafowl feather crests. Crests were first glued onto balsa wood blocks, which were then mounted on a mechanical shaker driven by a function generator that produced a sine wave output with a linear ramp in the frequency of shaking. The resulting motions of the crest flags and the shaker were measured using high-speed video. (B) Feather samples from Table S1 measured for comparison with peafowl crest vibrational resonant frequencies (not shown to scale): (i), (ii) peacock mantle feathers; (iii) short peacock eyespot feather; (iv), (v) peafowl body semiplumes; (vi) peacock wing covert; (vii) Himalayan monal crest feather); (viii) yellow crested cockatoo crest feather; (ix), (x) Victoria crowned pigeon crest feathers; (xi) golden pheasant crest feather.

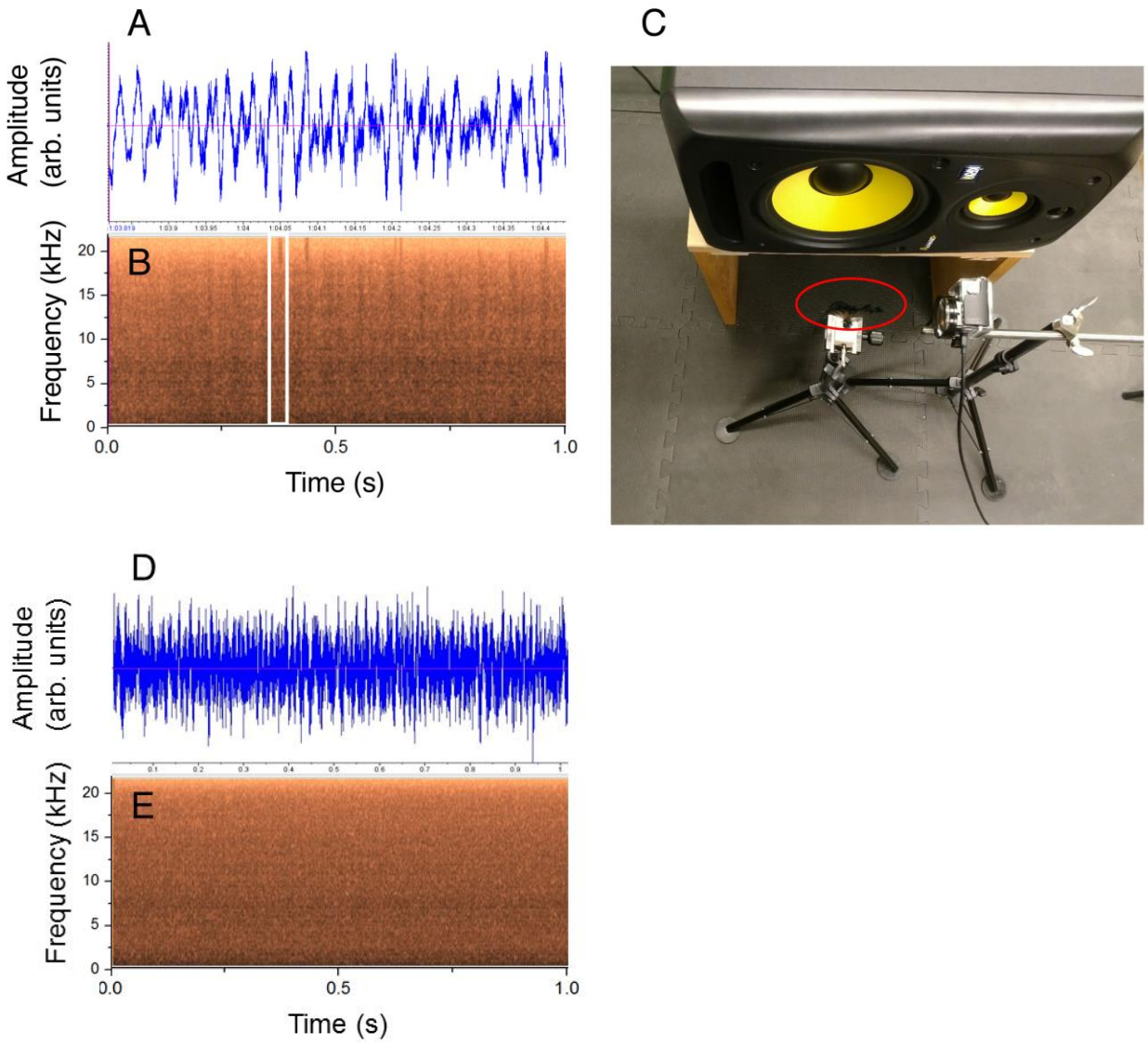

Fig. S2. Example audio and apparatus used for measuring the vibrational response of peafowl feather crests during audio playback of peacock train-rattling mechanical sounds. (A-B) An example waveform and spectrogram for one of the playback stimulus tracks of peacock train-rattling sounds. The waveform (A) and spectrogram (B) were generated from a re-recording made of the playback stimulus, to ensure that features of the playback stimulus matched those of the original recording from Dakin et al. (2016). The white box in (B) highlights a single rattle note in the train-rattling spectrogram. (C) Playback apparatus viewed from above. The crest sample (red ellipse) was exposed to the flow near-field of a loudspeaker (top) that played back peacock train-rattling sounds. The resulting motions of the crest flags were measured using a high-speed video camera (located to the right of the ellipse). (D-E) Waveform and spectrogram of the white noise control played back through the same audio system used for train-rattling playbacks. This illustrates the resemblance between the broad-band frequency spectrum of the white noise control (E) and the rattle notes (B). However, the white noise control lacks modulation at the low frequencies characteristic of displays.

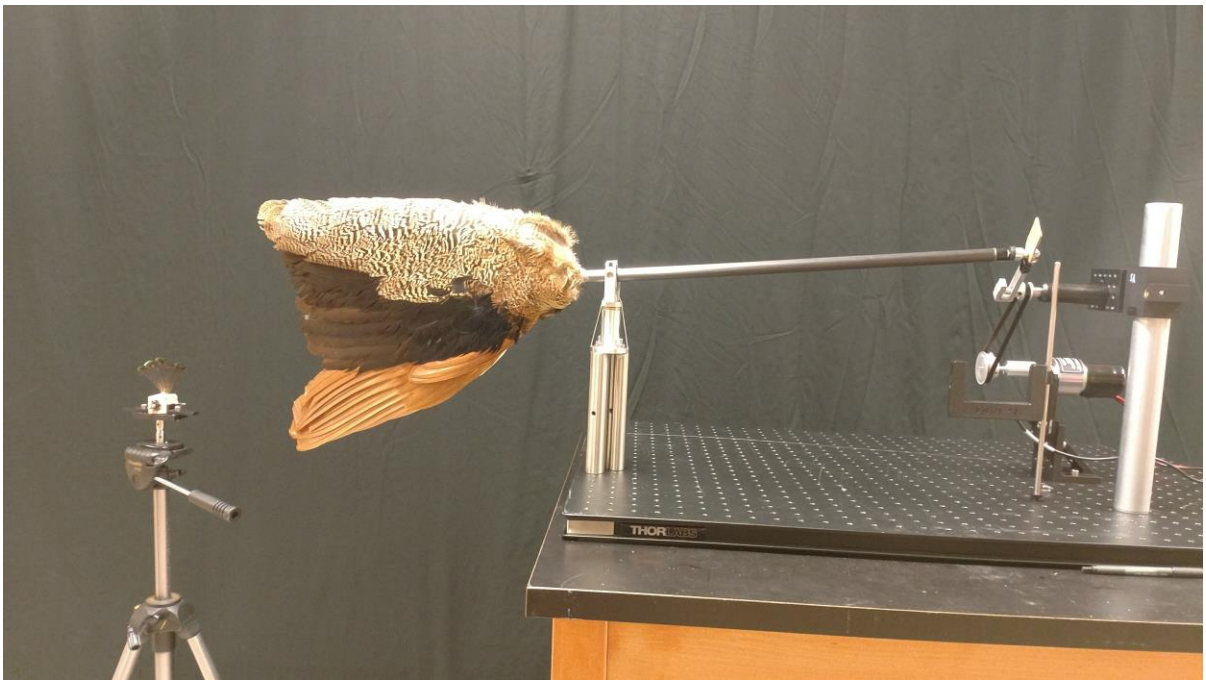

Fig. S3. Peacock wing-shaking displays were simulated using a peacock wing mounted on a carbon fiber rod. The rod was rotated at approximately 5 Hz (a typical wing-shaking frequency) about a clevis joint located at the wing's shoulder joint, ensuring that the plane of the wing's surface remained vertical while the tips circumscribed a 14 cm diameter circle. Peahen crests were positioned in the region of maximum airflow at distances ≤ 90 cm (50 cm shown here) from the wingtips. The resulting crest motion was filmed using high-speed video.

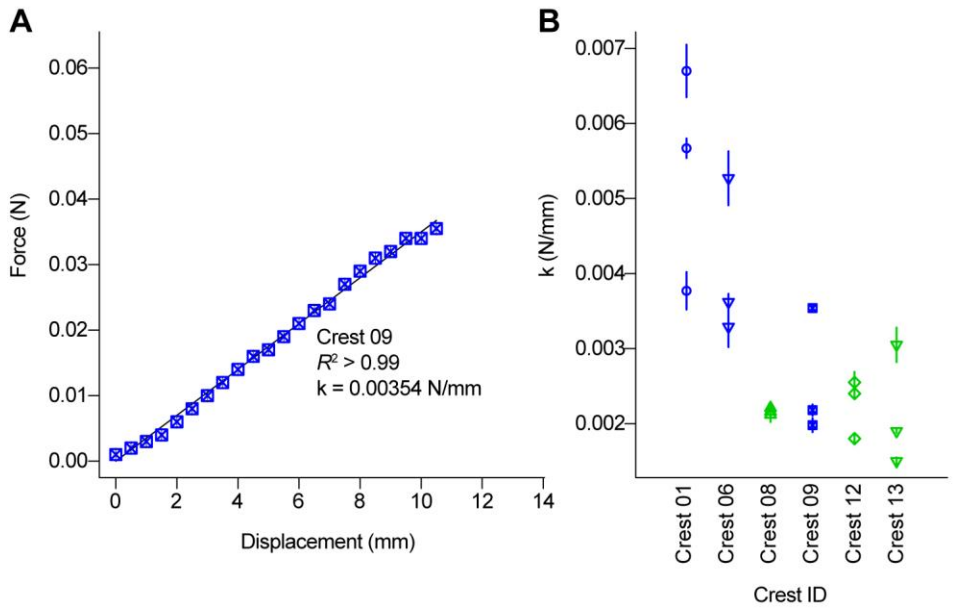

Fig. S4. Bending spring constant, k, of peafowl crests. Force-displacement trials were performed three times each for n = 3 male and n = 3 female crests, respectively. The bending spring constant, k, was calculated from the slope of linear model fits to the resulting force-displacement data from each trial. The example in (A) shows data from a single trial on peacock Crest 09 to illustrate the linearity of the response, with symbols scaled to span y-axis measurement error. (B) Values of k from each of three trials on the total n = 6 crests. Each crest sample is denoted by a different symbol-color combination, following Figs. 2-3 of the main text, and ordered left to right by decreasing mean k value. Blue data are male (peacock) crests and green data are female (peahen) crests.

Table S1. Individual feathers used in the vibrational resonant measurements for comparison with values shown in Fig. 3 for peafowl crests.

Species	Feather type	Rachis length (cm) (+/- 0.05 cm 95% CI)
Indian peafowl male	Body contour semiplume	3.94
Indian peafowl male	Body contour semiplume	5.95
Indian peafowl male	Wing covert	10.67
Indian peafowl male	mantle	5.15
Indian peafowl male	mantle	7.00
Indian peafowl male	train eyespot	11.50
Victoria crowned pigeon	crest	6.30
Victoria crowned pigeon	crest	12.50
Himalayan monal	crest	5.50
Golden pheasant	crest	5.00
Yellow-crested cockatoo	crest	10.00

Table S2. Sound pressure levels (SPL) of avian wingbeats during flight and wing-beating displays measured in previous studies.

Bird species	SPL (dB)	Distance (m)	Reference
Eastern phoebes, *Sayornis phoebe*	64-66 dB SPL at 1 kHz	1.2 m	Fournier, J.P., Dawson, J.W., Mikhail, A., & Yack, J.E. (2013). If a bird flies in the forest, does an insect hear it? Biology letters 9(5): 20130319.
Black-capped chickadees, *Poecile atricapillus*	54-60 dB SPL at 25 kHz	1.2 m	Fournier, J.P., Dawson, J.W., Mikhail, A., & Yack, J.E. (2013). If a bird flies in the forest, does an insect hear it? Biology letters 9(5): 20130319.
Crested pigeons, *Ocyphaps lophotes*	≤ 67.6 dB SPL	1.0 m	Hingee, M. & Magrath, R.D. (2009) Flights of fear: a mechanical wing whistle sounds the alarm in a flocking bird. Proceedings of the Royal Society of London B: rspb20091110.
Ruffed grouse, *Bonasa umbellus* (a wing-beating display)	66.2 dB SPL, bandwidth 300 Hz to 8 kHz, frequency weighting not reported	1.0 m	Garcia, M., Charrier, I., & Iwaniuk, A.N. (2012) Directionality of the drumming display of the ruffed grouse. The Condor 114(3): 500-506.

Table S3. Wingflap frequencies of adult peacocks during level and ascending flight.

Source	Number of individuals	Wingflap frequency (Hz)
https://www.youtube.com/watch?v=HvY_1wFSFsQ accessed September 28, 2017	1	4.92
https://www.youtube.com/watch?v=7gxQwm4MWns accessed September 28, 2017	1	4.16
https://www.youtube.com/watch?v=U55iMIiI_k0 accessed September 28, 2017	1	6.43
https://www.youtube.com/watch?v=kZe0jLkeMuk accessed September 28, 2017	1	4.42
https://www.youtube.com/watch?v=FrMQs7OwWC8 accessed September 28, 2017	3	6.36 6.00 5.55
https://www.youtube.com/watch?v=A5xSgaXDkTY accessed September 28, 2017	2	5.81 6.15

Table S4. Species in which both sexes have crests of flexible feathers and the male also performs a shaking display. There are many bird species wherein both sexes have a flexible feather crest. To understand the taxonomic breadth of birds that have shaking displays in addition to the crest, we used natural history resources including photos, videos and descriptive accounts of appearance and behavior. We documented at least 35 species across 10 different orders in which the females exhibit flexible feather crests and the males are known to perform shaking displays.

Order	Species	Common name
Accipitriformes	*Sagittarius serpentarius*	Secretary bird
Cariamiformes	*Cariama cristata*	Crested cariama
Columbiformes	*Geophaps plumifera*	Spinifex pigeon
	Goura cristata	Western crowned pigeon
	Goura scheepmakeri	Southern crowned pigeon
	Goura victoria	Victoria crowned pigeon
	Ocyphaps lophotes	Crested pigeon
Galliformes	*Afropavo congensis*	Congo peafowl
	Argusianus argus	Great argus
	Colinus cristatus	Crested bobwhite
	Leipoa ocellata	Malleefowl
	Lophophorus impejanus	Himalayan monal
	Lophura ignita	Crested fireback
	Lophura leucomelanos	Kalij pheasant
	Pavo cristatus	Indian peafowl
	Pavo muticus	Green peafowl
	Polyplectron bicalcaratum	Gray peacock pheasant
	Polyplectron malacense	Malayan peacock pheasant
	Polyplectron napoleonis	Palawan peacock pheasant
	Polyplectron schleiermacheri	Bornean peacock pheasant
	Rheinardia ocellata	Crested argus
	Tetrao urogallus	Western capercaillie
Gruiformes	*Balearica pavonina*	Black crowned crane
	Balearica regulorum	Gray crowned crane
Opisthocomiformes	*Opisthocomus hoazin*	Hoatzin
Passeriformes	*Baeolophus bicolor*	Tufted titmouse
	Cardinalis cardinalis	Northern cardinal
	Onychorhynchus coronatus	Royal flycatcher
	Prionops plumatus	White-crested helmetshrike
	Pycnonotus jocosus	Red-whiskered bulbul
	Rupicola peruvianus	Andean cock-of-the-rock
Pelicaniformes	*Phalacrocorax auritus*	Double-crested cormorant
	Phalacrocorax carbo	Great cormorant
Suliformes	*Anhinga anhinga*	Anhinga
Tinamiformes	*Eudromia elegans*	Elegant crested tinamou