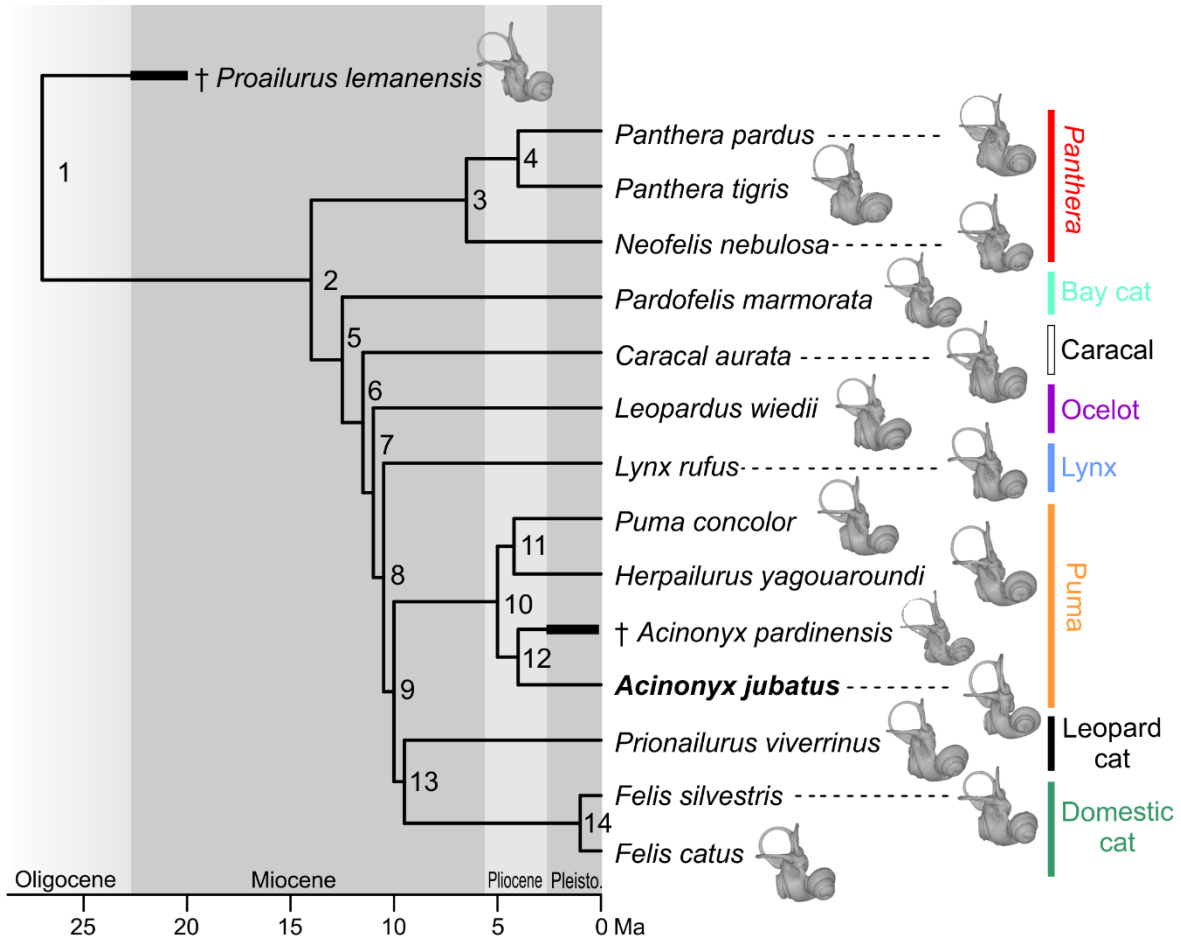


Supporting Information for

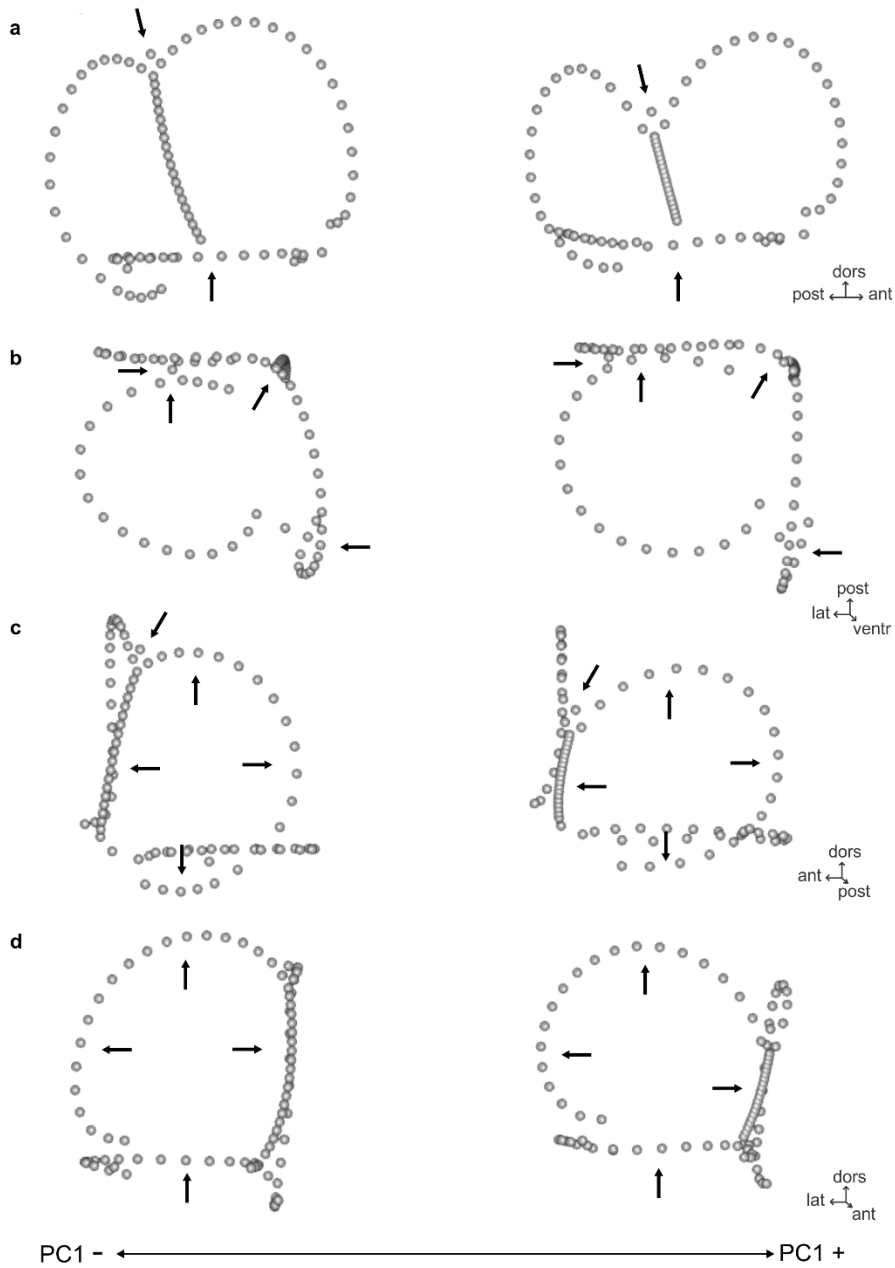
Recent inner ear specialization for high-speed hunting in cheetahs

Camille Grohé, Beatrice Lee, and John J. Flynn

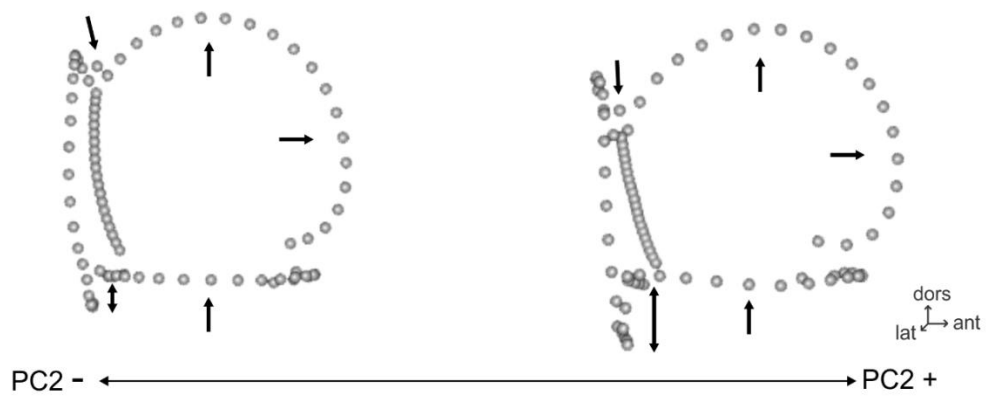
Supplementary Figure 1. Consensus phylogeny of Felidae. Node numbers correspond to divergence age estimates in Supplementary Table 1. Stratigraphic occurrences are 23.03-20 Ma (Oligo-Miocene to early Miocene) for *Proailurus lemanensis* and 2.58-0.126 Ma (early-middle Pleistocene) for *Acinonyx pardinensis*. Bony labyrinth representations not to scale.



Supplementary Figure 2. Visualization of shape changes in felids for the negative and positive values of PC1. Bony labyrinth in lateral (**a**), dorsal (**b**), posterior (**c**) and anterior (**d**) views (associated with Fig. 1c). Orientation of the bony labyrinth: ant, anterior; dors, dorsal; lat, lateral; post, posterior; ventr, ventral. Arrows highlight shape features discussed in the text.



Supplementary Figure 3. Visualization of shape changes in felids for the negative and positive values of PC2. Bony labyrinth in lateroposterior view (associated with Fig. 1c). Orientation of the bony labyrinth: ant, anterior; dors, dorsal; lat, lateral. Arrows highlight shape features discussed in the text.



Supplementary Table 1. Divergence age estimates for felids (associated with Supplementary Fig. 1).

Node number (this study)	Node number ¹	Age of nodes (Ma)	References	Descending nodes (NA is used when no OTUs descend from the node)
1	103	27	2, 3	† <i>Proailurus lemanensis</i> -Felidae
2	135	14	3	Felinae
3	170	6.5	4	<i>Panthera-Neofelis</i>
4	172	4	3	<i>Panthera</i>
5	136	12.5	3, 4	NA
6	137	11.5	4	NA
7	138	11	4	NA
8	139	10.5	4	NA
9	140	10	4	NA
10	152	5	4	<i>Puma-Acinonyx-Miracinonyx</i>
11	156	4.2	4	<i>Herpailurus yagouaroundi</i>
12	155	4	5	<i>Acinonyx jubatus</i> /† <i>A. pardinensis</i>
13	141	9.5	4	NA
14	147	1	4	<i>Felis catus</i> / <i>F. silvestris</i>

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Supplementary Table 2. List of the specimens analysed, and associated CT data information. Abbreviations for specimens are: AMNH, American Museum of Natural History, New York; M- and MO-, AMNH Mammalogy collection; FM, AMNH Fossil Mammals collection; F:AM, AMNH Frick Fossil Mammals collection; CCEC, Centre de Conservation et d'Étude des Collections, Musée des confluences, Lyon, France; MNHN F, Fossils from the Muséum d'Histoire Naturelle of Paris, France; SG-, collection of Saint-Gérard-le-Puy. Subspecies are based on the geographic origin of specimens for *Acinonyx jubatus*³. Extinct species are marked by the dagger symbol (†). Abbreviations: μm , micrometer; kV, kilovolt; mA, milliampere; L, left; R, right.

Species	Common name	Specimen number	Stage	Voxel size (μm)	Voltage (kV)	Amperage (mA)	Inner ear	Geographical origin	Sex
<i>Acinonyx jubatus</i>	Cheetah	AMNH FM 145070	adult	0.04004	120	180	L	unknown	unknown
<i>Acinonyx jubatus</i>	Cheetah	AMNH FM 145071	adult	0.08042	140	170	R	unknown	unknown
<i>Acinonyx jubatus soemeringii</i>	Northeast cheetah	AMNH M-90255	adult	0.06788	140	170	R	60 miles South of Harrar, Ethiopia	male
<i>Acinonyx jubatus raineyi</i>	Tanzanian cheetah	AMNH M-27897	adult	0.08224	130	170	R	Nyamusi, Nyanza Province, Kenya	male
<i>Acinonyx jubatus raineyi</i>	Tanzanian cheetah	AMNH M-161139	adult	0.06591	130	170	R	25 miles east Ngorongoro Crater, Arusha, Tanzania	male
<i>Acinonyx jubatus jubatus</i>	South African cheetah	AMNH M-119655	adult	0.0646	130	170	R	Tambara District, Mozambique	female

<i>Acinonyx jubatus jubatus</i>	South African cheetah	AMNH M-80618	juvenile	0.06476	130	170	R	Chitau, Bié Province, Angola	female
† <i>Acinonyx pardinensis</i>	'Giant' cheetah	CCEC-161825	adult	0.05	180	30	R	Saint Vallier, France	unknown
<i>Caracal aurata</i>	Golden cat	AMNH M-51996	adult	0.05662	130	170	R	Kenge, Democratic Republic of the Congo	male
<i>Felis silvestris lybica</i>	African wildcat	AMNH M-81233	adult	0.04872	130	170	R	Ethiopia	male
<i>Felis catus</i>	Domestic cat	AMNH F:AM 145069	juvenile	0.05077	120	160	R		unknown
<i>Leopardus wiedii</i>	Margay	AMNH M-95085	adult	0.05372	130	170	R	Santarém, Pará state, Brazil	male
<i>Lynx rufus</i>	Bobcat	AMNH M-24225	adult	0.05683	140	170	R	Brownsville, Cameron County, Texas	unknown
<i>Neofelis nebulosa</i>	Clouded leopard	AMNH M-22919	adult	0.09764	170	300	R	Central Park zoo, New York City	unknown
<i>Panthera pardus</i>	Leopard	AMNH M-113745	adult	0.136	160	170	R	Madras, India	male
<i>Panthera tigris</i>	Tiger	AMNH M-45519	adult	0.12025	160	150	R	Futsing, Fujian Province, China	male
<i>Pardofelis marmorata</i>	Marbled cat	AMNH M-102844	adult	0.0484	130	170	R	Sumatra, Indonesia	male
† <i>Proailurus lemanensis</i>		MNHN F-SG3509a	adult	0.05551	125	310	R	Saint-Gerand-Le-Puy, France	unknown
<i>Prionailurus viverrinus</i>	Fishing cat	AMNH M-102691	adult	0.05662	130	170	R	Java, Indonesia	male
<i>Puma concolor</i>	Puma	AMNH MO-6677	adult	0.095	160	180	R	Mascota, Jalisco state, Mexico	male

<i>Herpailurus yagouarondi</i>	Jaguarundi	AMNH M- 24853	adult	0.05419	120	150	R	Escuinapa, Sinaloa state, Mexico	male
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Supplementary Table 3. Volumetric measurements of the bony labyrinths and body mass estimation of felid specimens based on the following equation⁵²: $\log_{10}BM = (\log_{10}CBL - 1.723)/0.345$, with BM, Body Mass (kg) and CBL, CondylloBasal Length (mm). Vol, Volume (mm³); BL, Bony Labyrinth; VS, Vestibular System; CS, Cochlear System; % Vol VS= (Vol BL/Vol VS) × 100. BM is in grams. Extinct species are marked by the dagger symbol (†). See Methods for details.

Species	Specimen number	Vol BL	Vol VS	Vol CS	% Vol VS	CBL	BM
<i>Acinonyx jubatus</i>	AMNH FM 145070	109.1	44.83	64.27	41.1	153.6	22037.5
<i>Acinonyx jubatus</i>	AMNH FM 145071	98.78	43.14	55.64	43.7	152	21378.7
<i>Acinonyx jubatus soemerringii</i>	AMNH M-90255	124.13	48.17	75.96	38.8	135.4	15289.8
<i>Acinonyx jubatus raineyi</i>	AMNH M-27897	117.17	44.82	72.35	38.2	192.7	42524.8
<i>Acinonyx jubatus raineyi</i>	AMNH M-161139	120.07	47.06	73.01	39.2	166.93	28049.5
<i>Acinonyx jubatus jubatus</i>	AMNH M-119655	126.52	48.06	78.46	38	168.6	28870.7
<i>Acinonyx jubatus jubatus</i>	AMNH M-80618	127.64	51.35	76.29	40.2	103.1	6939.52
<i>Caracal aurata</i>	AMNH M-51996	96.68	26.78	69.9	27.7	99	6169.46
<i>Felis catus</i>	AMNH F:AM 145069	57.15	19.04	38.11	33.3	61	1515.89
<i>Felis silvestris</i>	AMNH M-81233	71.75	21.68	50.07	30.2	88	4385.09
<i>Herpailurus yagouaroundi</i>	AMNH M-24853	62.53	22.36	40.17	35.8	99.69	6294.92
<i>Leopardus wiedii</i>	AMNH M-95085	73.79	19.56	54.23	26.5	89	4531.09
<i>Lynx rufus</i>	AMNH M-24225	99.75	34.88	64.87	35	120	10774.8
<i>Neofelis nebulosa</i>	AMNH M-22919	105.81	34.97	70.84	33	157.8	23829.9
<i>Panthera pardus</i>	AMNH M-113745	161.22	51.49	109.73	31.9	161.36	25421.8
<i>Panthera tigris</i>	AMNH M-45519	241.99	79.14	162.85	32.7	272	115483
<i>Pardofelis marmorata</i>	AMNH M-102844	66.74	21.23	45.51	31.8	95	5474.31
<i>Prionailurus viverrinus</i>	AMNH M-102691	94.68	27.15	67.53	28.7	117.6	10162
<i>Puma concolor</i>	AMNH MO-6677	149.86	47.76	102.1	31.9	167.7	28426.2
† <i>Acinonyx pardinensis</i>	CCEC-161825	124.41	43.18	81.23	34.7	165	27119.8
† <i>Proailurus lemanensis</i>	MNHN F-SG3509a	62.04	20.16	41.88	32.5	143	17912.2

Supplementary Table 4. Log-transformed Vol VS (Volume of the Vestibular System in mm³) and BM (Body mass in grams) used for the least squares regression model (see Methods) and associated residuals. The model has the following equation: $\log_{10}\text{Vol VS} = 0.36192 \times \log_{10}\text{BM} + 0.01989$. $R^2 = 0.772$; Standard error = 0.05455; p-value = 1.627×10^{-5} . Extinct species are marked by the dagger symbol (†).

	log₁₀BM	log₁₀ Vol VS	Residuals
<i>Acinonyx jubatus</i>	4.3194	1.6694	0.0862
<i>Caracal aurata</i>	3.7902	1.4278	0.0362
<i>Felis catus</i>	3.1807	1.2797	0.1086
<i>Felis silvestris</i>	3.642	1.3361	-0.0019
<i>Herpailurus yagouaroundi</i>	3.799	1.3495	-0.0453
<i>Leopardus wiedii</i>	3.6562	1.2914	-0.0518
<i>Lynx rufus</i>	4.0324	1.5426	0.0633
<i>Neofelis nebulosa</i>	4.3771	1.5437	-0.0603
<i>Panthera pardus</i>	4.4052	1.7117	0.0975
<i>Panthera tigris</i>	5.0625	1.8984	0.0463
<i>Pardofelis marmorata</i>	3.7383	1.3269	-0.0459
<i>Prionailurus viverrinus</i>	4.007	1.4338	-0.0363
<i>Puma concolor</i>	4.4537	1.6791	0.0473
† <i>Acinonyx pardinensis</i>	4.4333	1.6353	0.0109
† <i>Proailurus lemanensis</i>	4.2531	1.3045	-0.2547

Supplementary Table 5. Definition of the 3D landmarks and semilandmarks in the geometric morphometric analysis. SC, Semicircular Canal.

No	Type	Definition
1	Landmark	Bifurcation point of the lateral and anterior SC
2	Landmark	Bifurcation point of the lateral and posterior SC
3	Landmark	Bifurcation point of the anterior and posterior SC
4 to 23	Semilandmarks	Curve placed at the center of the anterior SC
24 to 43	Semilandmarks	Curve placed at the center of the lateral SC
44 to 63	Semilandmarks	Curve placed at the center of the posterior SC
64 to 83	Semilandmarks	Curve placed at the center of the common crus

Supplementary Table 6. Linear and angular measurements of the semicircular canals of felid specimens. L, length; W, Width; ASC, Anterior Semicircular Canal; LSC, Lateral Semicircular Canal; PSC, Posterior Semicircular Canal. Extinct species are marked by the dagger symbol (†). See Methods for details.

Species	Specimen number	ASC L	ASC W	LSC L	LSC W	PSC L	PSC W	Angle ASC/LSC	Angle LSC/PSC	Angle ASC/PSC
<i>Acinonyx jubatus</i>	AMNH FM 145070	4.97	5.28	4.39	4.14	5.04	4.5	88.63	96.56	113.41
<i>Acinonyx jubatus</i>	AMNH FM 145071	5.15	5.35	4.28	4.18	5.54	4.64	88.62	93.78	109.48
<i>Acinonyx jubatus soemerringii</i>	AMNH M-90255	5.03	5.44	4.41	4.3	5.07	4.44	90.67	96.4	111
<i>Acinonyx jubatus raineyi</i>	AMNH M-27897	5.23	5.36	4.56	4.41	5.21	4.53	88.93	92.69	111.37
<i>Acinonyx jubatus raineyi</i>	AMNH M-161139	5.53	5.53	4.61	4.24	5.37	4.67	90.76	92.61	112.17
<i>Acinonyx jubatus jubatus</i>	AMNH M-119655	5.25	5.34	4.64	4.48	5.22	4.86	88.97	91.04	109.15
<i>Acinonyx jubatus jubatus</i>	AMNH M-80618	5.29	5.31	4.29	4.63	5.46	4.76	91.91	90.41	113.67
<i>Caracal aurata</i>	AMNH M-51996	3.89	4.78	4.5	3.99	4.27	4.24	90.52	87.14	88.81
<i>Felis catus</i>	AMNH F:AM 145069	2.86	3.77	3.47	3.54	3.1	3.37	90.44	95.91	89.55
<i>Felis silvestris</i>	AMNH M-81233	3.15	3.93	3.58	3.64	3.17	3.39	85.51	93.1	88.51
<i>Herpailurus yagouaroundi</i>	AMNH M-24853	3.7	4.14	3.21	3.99	4.15	4.16	89.19	91.32	93.48
<i>Leopardus wiedii</i>	AMNH M-95085	3.62	4.16	3.79	3.49	3.41	3.91	86.24	95.19	90.65
<i>Lynx rufus</i>	AMNH M-24225	4.04	4.88	4.5	3.96	4.43	4.55	87	87.73	89.8
<i>Neofelis nebulosa</i>	AMNH M-22919	4.91	5.56	4.57	4.28	4.92	4.94	86.11	95.7	85.48
<i>Panthera pardus</i>	AMNH M-113745	5.45	6.14	5.21	5.3	5.01	5.68	89.42	84.76	89.27
<i>Panthera tigris</i>	AMNH M-45519	5.39	6.95	6.11	5.95	6.26	6.35	90.15	87.06	96.03
<i>Pardofelis marmorata</i>	AMNH M-102844	3.57	4.3	3.86	3.76	3.78	4.03	89.46	90.28	96.66
<i>Prionailurus viverrinus</i>	AMNH M-102691	3.98	4.26	3.83	3.66	3.93	4	90.67	93.48	89.96
<i>Puma concolor</i>	AMNH MO-6677	4.93	5.96	5	4.69	5.42	5.46	90.21	93.17	92.73
† <i>Acinonyx pardinensis</i>	CCEC-161825	5.56	5.63	5.59	5.22	5.22	5.59	84.76	91.31	92.42
† <i>Proailurus lemanensis</i>	MNHN F-SG3509a	4.42	4.54	3.98	3.52	3.47	4.31	82.755	92.49	91.83