
Supplementary information

Chicago *Archaeopteryx* informs on the early evolution of the avian bauplan

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SUPPLEMENTARY INFORMATION

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1. Supplementary methods

Scan parameters

Full skeleton scan: NSI scanner. Fein Focus High Power source, 220 kV, 0.105 mA, brass filter, Perkin Elmer detector, 0.25 pF gain, 1 fps, 1x1 binning, source to object 582.015 mm, source to detector 886.232 mm, non-continuous CT scan, no frames averaged, 0 skip frames, 2x2 SubpiX scan, 12000 projections, 5 gain calibrations, 15 mm calibration phantom, data range [-20, 60] adjusted grayscale values, beam-hardening correction = 0.6. Post-reconstruction ring correction applied by Dave Edey using parameters oversample = 2, radial bin width = 21, sectors = 128, minimum arc length = 0.5, angular bin width = 9, angular screening factor = 2.5. Voxel size = 65.7 μm . Total slices = 3699.

Skull scan: NSI scanner. Fein Focus High Power source, 220 kV, 0.2 mA, brass filter, Perkin Elmer detector, 0.25 pF gain, 1 fps, 1x1 binning, source to object 208.887 mm, source to detector 1301.305 mm, non-continuous CT scan, 2 frames averaged, 0 skip frames, 8000 projections, 5 gain calibrations, 5 mm calibration phantom, data range [-20, 500] adjusted grayscale values, beam-hardening correction = 0.5. Post-reconstruction ring correction applied by Jessie Maisano using parameters oversample = 2, radial bin width = 21, sectors = 128, minimum arc length = 0.5, angular bin width = 9, angular screening factor = 2. Voxel size = 32.1 μm . Total slices = 1794.

Comments on the segmentation: Due to the high density of the Solnhofen Limestone which makes segmentation difficult, few specimens have been scanned with meaningful results¹⁻⁴. In this case of *Archaeopteryx*, segmentation is exacerbated by the very thin bone walls of the skeleton. Some morphological details are obscured by the relatively low resolution of the scans (primarily affecting thin elements like cranial elements but also the neural spines on the dorsal vertebrae, the ischia, and the ascending process of the astragalus), as well as the broken contacts between bones split between the slab and counterslabs prior to acquisition (most affecting the forelimbs and the left foot), and the presence of calcite crystals overlapping with some parts of the skeleton (e.g., where the femora articulates with the pelvis). Delicate and complex structures like the vertebrae were very difficult to segment out, especially the postaxial cervicals, which were split between the main slab and one of the counterslabs. Still, the rib attached to C6 is visible in the scans. This rib was damaged and then intentionally removed by the contract preparator without permission from the FMNH and thus does not appear in prepared the physical specimen. The ischia, although clearly visible in the slab, are nearly impossible to determine in the scans due to their overlap with each other and the left femur and the fact they are mediolaterally thin. As such, it was impossible to segment the left ischium. The ascending process of the astragalus was also impossible to discern in the CT scans because of how thin this structure is. The distal articular surfaces of the minor digit phalanges, and to a lesser degree the

major digit phalanges, are very hard to discern in the scans potentially suggesting they were poorly ossified.

2. Supplementary Discussion

Taxonomic referral of FMNH PA 830 to Archaeopteryx

The taxonomy of the 13 previously described specimens of *Archaeopteryx* is debatable and most specimens, especially the older, more incomplete, and poorly preserved ones, have at some time been considered to be a distinct taxon separate from *Archaeopteryx lithographica*⁵. While most authors consider all specimens to represent a single genus, *Archaeopteryx*, the Solnhofen specimen is considered by some to represent a separate genus – *Wellnhoferia* – based on its unusual pedal phalangeal formula⁶. Recently, the poorly preserved and very incomplete Haarlem specimen was reidentified as a non-avian paravian, *Ostromia*⁷. In the most recent discussion of *Archaeopteryx* taxonomy, all specimens except for the Haarlem specimen were referred to *Archaeopteryx* sp.⁸. We consider that purported differences between *Archaeopteryx* and ‘*Ostromia*’ cannot be verified due to the poor preservation of the Haarlem specimen. Within *Archaeopteryx*, some authors consider the possibility of two distinct species⁹: *A. lithographica*¹⁰ and *A. siemensii*¹¹ (*A. bavarica* being recently considered a junior synonym of the latter⁹). Pending an in-depth taxonomic review of all known specimens, we refer FMNH PA 830 to *Archaeopteryx* sp. following the differential diagnosis put forth by Rauhut et al.⁸

Rauhut et al.⁸ note that there are currently no definitively known autapomorphies of *Archaeopteryx* but that this genus can be readily diagnosed by a unique combination of characters, all of which can be observed in the Chicago specimen. FMNH PA 830 can be referred to *Archaeopteryx* based on the unique combination of the following features: depressed rim around the margin of the exit of cranial nerve V (trigeminal); sharply incised notch between the postorbital and quadratojugal processes of the jugal; slender quadratojugal process of the jugal; eight to nine maxillary teeth; mandibular fenestra absent; unique dental morphology with parallel mesial and distal margins basally and weakly recurved apices separated by a bulbous section mid-crown; axial column consisting of nine cervicals, 14 dorsals, five sacrals, and 24 caudals; and an intermediate process on the dorsal margin of the ischium (modified from⁸). Note that Chicago specimen indicates the tail actually consists of 24 vertebrae and not 23 as previously hypothesized⁸. We tentatively suggest that in the cranial process on the ventrodorsal process of the ischium observed in this specimen for the first time may be an autapomorphy of *Archaeopteryx* but the delicate nature of this feature means it is unlikely to be useful due to its rare preservation and thus the possibility of this feature being more widespread among paravians.

Foot pads

Archaeopteryx preserves traces of small, evenly sized, closely spaced reticulate scales demarcating plantar projecting joint pads separated by phalanx pads of similar length. In contrast, the joint pads in *Microraptor* are hypertrophied, similar to birds of prey today (e.g., accipiters, falconids)¹²⁻¹⁴ (Extended Data Fig. 5). These plantar expanded pads both increase the surface area that makes contact with prey and allows for greater pressure exertion on prey when the pedal digits are flexed (closed, gripping)¹⁴⁻¹⁷. The phalanx pads between these joint pads are nearly absent in *Microraptor*, with joint plantar pads terminating at the beginning of the next distally proceeding joint pad. Features of the foot pads themselves suggest arboreal and raptorial behaviors in *Microraptor*^{13,18}. The phalanx pads are longer in *Anchiornis*¹², but still short compared to *Archaeopteryx*. This indicates the feet *Archaeopteryx* were relatively better

adapted for terrestrial locomotion compared to *Anchiornis*, which most likely reflects the difference in environment occupied by these two taxa, with the Yanliao Biota representing a temperate forested environment¹⁶⁻¹⁹.

Both *Sapeornis* (41HIII0405) and *Confuciusornis* (IVPP V13156) exhibit tightly packed scales and rather thick, weakly separated joint plantar pads^{20,21}. Other than the phalanx pad of the hallux in *Sapeornis*, joint pads are very reduced in these taxa, similar to *Microraptor* and to a lesser degree *Anchiornis*, but contrasting with the condition in *Archaeopteryx*. In the ornithuromorph *Yanornis*, the foot pads have subequal plantar projection¹². However, as preservation of the foot is in dorsolaterally aspect, the true extend of the joint pads is difficult to determine. In contrast to *Archaeopteryx*, the scales in *Yanornis* are loosely packed together, and exhibit little discernable inter-joint pads. However, like *Archaeopteryx*, the decrease in proximodistal length among each bone within the pedal digits signals terrestrial locomotion, more so than arboreal behavior^{19,22,23}.

Tertials

Tertial feathers are a specific group of feathers found on the wings of birds, absent only in taxa that have completely reduced their remiges (e.g., apterygiforms). These may be part of the innermost flight feathers and either attach to the distal humerus (sometimes referred to as humerals; true tertials) and/or the proximal part of the ulna (olecranon or skin surrounding the olecranon), in which case they are considered specialized secondaries (although there is little consensus concerning these terminologies among ornithologists)²⁴. Tertials are thus positioned between the bird's body and other secondary feathers on the wing²⁴. Tertials usually differ from the other secondary remiges in their color, shape (e.g., the degree of vane asymmetry), and molt sequence^{25,26}. Tertial feathers may serve several important functions in birds, including (1) flight assistance [e.g., Albatrosses (Diomedidae), Pelicans (Pelecaniformes), Herons (Ardeidae), and Geese (Anatidae)²⁷], (2) protection^{25,28,29}, insulation and waterproofing [e.g., Wagtails (Motacillidae; Extended Data Fig. 3a) and Sandpipers (Scolopacidae; Extended Data Fig. 3b)], and (3) display, visual communication and camouflage [e.g., Cranes³⁰ (Gruidae; Extended Data Fig. 3c), Trumpeters (Psophiidae; Extended Data Fig. 3d) and Nightjars (Caprimulgidae)^{24,26}]. While tertial feathers do not form the main aerodynamic surface (formed by the primary and non-tertial secondary feathers), they play a supportive role in flight aerodynamics mainly by filling the gap between the wing and body²⁶. This is especially critical in birds with elongate humeri like pelicans and shearwaters. Tertials also help to smooth the airflow over the wing and reduce turbulence, which can improve flight efficiency and stability³¹. During flight, particularly at slower speeds or when taking off and landing, tertial feathers can help birds control their movements more precisely²⁷. In some taxa, it appears that tertials serve multiple functions such as aerodynamics by filling the gap between the wing and body but also camouflage (e.g., Strigidae).

The left wing reveals the presence of adjacent humeral tertials at least along the distal third of the humerus, in confirmation of Yalden³² who predicted the need for tertials in *Archaeopteryx* to compensate for the elongated humerus. Indeed, there are two ways to close the gap between the wing and the body: a shorter humerus or humeral tertials. Consistent with the unreduced morphology of the humerus in the Chicago *Archaeopteryx*, the humeral tertials would have served as part of the flight apparatus to create a continuous aerodynamic surface from the body to the primary remiges.

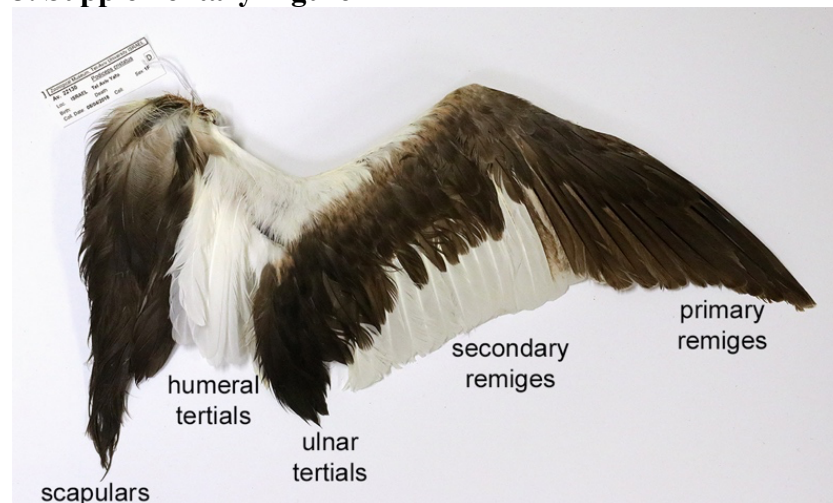
More surprising is the presence of multiple tertial feathers forming a large fan-shaped surface extending from near the joint between the ulna and the humerus in the Chicago *Archaeopteryx*. The area of the fan-created by these feathers is large compared to the area of the secondary feathers in the wings of volant modern birds (about 85% compared to a mean of 28% in the 218 neornithine species we examined (55 families), range = 11% - 56%; Supplemental Table 3). While some birds have elongate tertials, it is the surface area that is unique in *Archaeopteryx*.

Tertials have not been described in other Mesozoic birds. However, we observe that ulnar tertials are present in *Confuciusornis* (e.g., STM13-133) and enantiornithines (e.g., *Propteryx* STM7-43 and BMNHC-PH1060)³³, as in passerines and most other neornithines. In these taxa, the tertial surface area is proportionately smaller than in *Archaeopteryx* (20-30% of the secondary feather area in *Propteryx*) and these feathers are aligned with the other secondaries (not also forming a fan like in *Archaeopteryx*), which indicates their functional role was limited to filling the gap between the wing and the body, and/or to protect the distal wing feathers, as in many neornithines [e.g., Leaf Warblers (Phylloscopidae) and Reed Warblers (Acrocephalidae)]²⁵.

While the role of the humeral tertials was most likely primarily to close the wing gap and aid in flight, supported by their apparent absence in non-volant paravians, the large size and unusual fan-shaped morphology of the ulnar tertials in *Archaeopteryx* suggests these feathers may have also played a role in visual communication. Functional hypotheses are not mutually exclusive. Indeed, the tertials in *Archaeopteryx* may have served multiple functions. The unusual morphology in this taxon may potentially also be related to the unique form of flight utilized by this earliest known bird.

Although information concerning the function of the tertial feathers is mentioned in the ornithological literature, it seems to be based mostly on hypotheses and less on research²⁶. Future research that examines these ideas, particularly with comparative or phylogenetic tools, may improve our understanding of the function and early evolution of wing feathers in birds and pennaraptorans more broadly.

3. Supplementary Figure



Supplemental Figure 1. Right wing of a Great Crested Grebe (*Podiceps cristatus*, Podicipediformes) in dorsal view (AV-22130, Steinhardt Museum of Natural History). This taxon has an elongate humerus that has humeral and ulnar tertials.

4. Supplementary Tables

Supplementary Table 1. Measurements of the Chicago specimen (FMNH PA 830) as compared to the Eichstätt specimen. Measurements were taken using Fiji (ImageJ) to avoid damaging the specimen. All measurements are in millimeters. Measurements for the Eichstätt specimen were taken from Wellnhofer⁵. For comparing body size between these two small specimens we calculated the ratio of the Chicago specimen to the Eichstätt specimen; if both the right and left element were measured for the Chicago specimen, these values were averaged and then compared to the single measurement provided by Wellnhofer⁵. Note that the Chicago specimen has a slightly longer forelimb and slightly shorter hindlimb compared to the Eichstätt specimen.

Element	Chicago Specimen		Eichstätt	Chicago: Eichstätt
	Right	Left		
Skull	40.56		39	1.04
Mandible	35.73		36.5	0.98
Coracoid	11.5	10.31		
Scapula	23.38	21.72		
Humerus	41.3	40	41.5	0.96
Ulna	36.65	36.22	36.5	1
Radius	35.85	35.29	35	1.02
Alular metacarpal	5.62	5.45	5.5	1.01
Phalanx 1	15.38	15.19	15.6	
Phalanx 2	7.19	8.03	9.8	
Major metacarpal	18.776	19.23	17.8	1.07
Phalanx 1	10.675	10.82	10.2	
Phalanx 2	14.76	(10.57)	15.1	
Phalanx 3	7.45	-	10.8	
Minor metacarpal	17.286	17.72	16.5	1.06
Phalanx 1	4.215	3.85	4.2	
Phalanx 2	2.975	2.9	3	
Phalanx 3	9.83	9.69	9.8	
Phalanx 4	5.13	5.3	6.5	
Ilium	21.91			
Ischium	11.9			
Femur	36.14		37	0.98
Tibia	52.5		52.5	1
Fibula	48.3			
Metatarsal I	5.48		-	
Phalanx 1	5.15		5.9	
Phalanx 2	4.85		6	
Metatarsal II	26.21		28.3	0.93
Phalanx 1	6.5		7.3	
Phalanx 2	7.11		7.5	
Phalanx 3	7.06		9.9	
Metatarsal III	29.39		30.2	0.97
Phalanx 1	8.71		9.3	
Phalanx 2	7.27		7.8	
Phalanx 3	6.3		7	
Phalanx 4	6.19		8.7	
Metatarsal IV	27.59		27.3	1.01
Phalanx 1	6.04		6.4	
Phalanx 2	5.12		5.3	

Phalanx 3	4.51		5	
Phalanx 4	4.91		5.3	
Phalanx 5	4.96		7.1	
Metatarsal V	5.866		-	

Supplementary Table 2. Variation in the soft tissue of the ventral surface of the feet in Mesozoic paravians and direct evidence of diet. Note that ecology as inferred from foot pad morphology aligns consistently with known diets indicating foot pads are a strong indicator of ecology.

Taxon	Joint Pad	Phalanx Pad	Scales	Direct Evidence of Diet
<i>Anchiornis</i>	Proportionally long, deep	Reduced	Loosely-packed, varying in size, some with distal points	Lizard, fish ³⁴
<i>Microraptor</i>	Dorsoventrally deep	Nearly Absent	Loosely-packed, varying in size, some distal tapering	Birds, lizards ^{35,36} , mammals ³⁷ , fish ³⁸
<i>Sapeornis</i>	Dorsoventrally deep	Nearly Absent	Tightly-packed, uniformly sized, rounded margins	Herbivorous ³⁹
<i>Yanornis</i>	Dorsoventrally equal to phalanx pads	Dorsoventrally equal to joint pads	Tightly-packed, uniformly sized, rounded margins	Piscivory ^{40,41}
<i>Chicago Archaeopteryx</i>	Reduced	Proportionally long	Tightly-packed, uniformly sized, rounded margins	Unknown
<i>Confuciusornis</i>	Dorsoventrally deep	Reduced	Tightly-packed, uniformly sized, rounded margins	Unknown

Supplementary Table 3. The area of the tertials compared to the area of the secondary feathers among Neornithes. The values are calculated as a ratio between tertials and secondaries in the wings of 218 extant volant species sampling 55 families.

	Species	Family	Order	Number of ulnars	Number of humerals	Identified by (shape / color / shape and color)	% area (tertials/ secondaries)	
	Eurasian Sparrowhawk	<i>Accipiter nisus</i>	Accipitridae	Accipitriiformes	3	0	shape	0.15
	Golden Eagle	<i>Aquila chrysaetos</i>	Accipitridae	Accipitriiformes	3	0	shape and color	0.15
	Long-legged Buzzard	<i>Buteo rufinus</i>	Accipitridae	Accipitriiformes	3	0	shape	0.11
	European Honey-buzzard	<i>Pernis apivorus</i>	Accipitridae	Accipitriiformes	3	0	shape	0.12
	Green-winged Teal	<i>Anas crecca</i>	Anatidae	Anseriiformes	5	0	shape and color	0.56
	Mallard	<i>Anas platyrhynchos</i>	Anatidae	Anseriiformes	4	0	shape and color	0.37
	Eurasian Hoopoe	<i>Upupa epops</i>	Upupidae	Bucerotiiformes	3	0	shape and color	0.28
	Little Swift	<i>Apus affinis</i>	Apodidae	Caprimulgiformes	3	0	shape	0.26
	Common Nighthawk	<i>Chordeiles minor</i>	Caprimulgidae	Caprimulgiformes	3	0	shape and color	0.29
	Common Ringed Plover	<i>Charadrius hiaticula</i>	Charadriidae	Charadriiformes	6	0	shape and color	0.35
	Northern Lapwing	<i>Vanellus vanellus</i>	Charadriidae	Charadriiformes	5	0	shape and color	0.21
	Collared Pratincole	<i>Glareola pratincola</i>	Glareolidae	Charadriiformes	3	0	shape and color	0.24
	Caspian Tern	<i>Hydroprogne caspia</i>	Laridae	Charadriiformes	6	6	shape	0.29
	Black-winged Stilt	<i>Himantopus himantopus</i>	Recurvirostridae	Charadriiformes	5	0	shape	0.26

Little Stint	<i>Calidris minuta</i>	Scolopacidae	Charadriiformes	5	0	shape and color	0.28
European Turtle Dove	<i>Streptopelia turtur</i>	Columbidae	Columbiformes	3	0	shape and color	0.19
Common Kingfisher	<i>Alcedo atthis</i>	Alcedinidae	Coraciiformes	3	0	shape	0.27
White-throated Kingfisher	<i>Halcyon smyrnensis</i>	Alcedinidae	Coraciiformes	4	0	shape	0.14
European Roller	<i>Coracias garrulus</i>	Coraciidae	Coraciiformes	4	0	shape and color	0.25
European Bee-eater	<i>Merops apiaster</i>	Meropidae	Coraciiformes	3	0	shape and color	0.18
Arabian Green Bee-eater	<i>Merops cyanophrys</i>	Meropidae	Coraciiformes	3	0	shape and color	0.17
Great Spotted Cuckoo	<i>Clamator glandarius</i>	Cuculidae	Cuculiformes	3	0	shape	0.27
Peregrine Falcon	<i>Falco peregrinus</i>	Falconidae	Falconiformes	3	0	shape	0.29
Common Crane	<i>Grus grus</i>	Gruidae	Gruiformes	5	7	shape and color	0.41
Corncrake	<i>Crex crex</i>	Rallidae	Gruiformes	5	0	shape and color	0.49
Sora	<i>Porzana carolina</i>	Rallidae	Gruiformes	5	0	shape and color	0.48
Great Reed Warbler	<i>Acrocephalus arundinaceus</i>	Acrocephalidae	Passeriformes	3	0	shape	0.32
Moustached Warbler	<i>Acrocephalus melanopogon</i>	Acrocephalidae	Passeriformes	3	0	shape and color	0.37
Marsh Warbler	<i>Acrocephalus palustris</i>	Acrocephalidae	Passeriformes	3	0	shape	0.34
Sedge Warbler	<i>Acrocephalus schoenobaenus</i>	Acrocephalidae	Passeriformes	3	0	shape	0.34
Common Reed Warbler	<i>Acrocephalus scirpaceus</i>	Acrocephalidae	Passeriformes	3	0	shape	0.29
Clamorous Reed Warbler	<i>Acrocephalus stentoreus</i>	Acrocephalidae	Passeriformes	3	0	shape	0.30
Thick-billed Warbler	<i>Arundinax aedon</i>	Acrocephalidae	Passeriformes	3	0	shape	0.33
Upcher's Warbler	<i>Hippolais languida</i>	Acrocephalidae	Passeriformes	3	0	shape	0.23
Olive-tree Warbler	<i>Hippolais olivetorum</i>	Acrocephalidae	Passeriformes	3	0	shape	0.31
Eastern Olivaceous Warbler	<i>Iduna pallida</i>	Acrocephalidae	Passeriformes	3	0	shape	0.21
Greater Hoopoe-Lark	<i>Alaemon alaudipes</i>	Alaudidae	Passeriformes	3	0	shape and color	0.39
Eurasian Skylark	<i>Alauda arvensis</i>	Alaudidae	Passeriformes	3	0	shape and color	0.30
Oriental Skylark	<i>Alauda gulgula</i>	Alaudidae	Passeriformes	3	0	shape and color	0.31
Mediterranean Short-toed Lark	<i>Alaudala rufescens</i>	Alaudidae	Passeriformes	3	0	shape	0.24
Bar-tailed Lark	<i>Ammomanes cinctura</i>	Alaudidae	Passeriformes	3	0	shape and color	0.24
Desert Lark	<i>Ammomanes deserti</i>	Alaudidae	Passeriformes	3	0	shape and color	0.27
Arabian Lark	<i>Eremalauda eremodites</i>	Alaudidae	Passeriformes	3	0	shape and color	0.23
Shore Lark	<i>Eremophila alpestris</i>	Alaudidae	Passeriformes	3	0	shape	0.27
Temminck's Lark	<i>Eremophila bilopha</i>	Alaudidae	Passeriformes	3	0	shape and color	0.31
Crested Lark	<i>Galerida cristata</i>	Alaudidae	Passeriformes	4	0	shape and color	0.32
Woodlark	<i>Lullula arborea</i>	Alaudidae	Passeriformes	3	0	shape and color	0.35
Calandra Lark	<i>Melanocorypha calandra</i>	Alaudidae	Passeriformes	4	0	shape and color	0.27
Thick-billed Lark	<i>Ramphocoris clotbey</i>	Alaudidae	Passeriformes	3	0	shape and color	0.27
White-throated Dipper	<i>Cinclus cinclus</i>	Cinclidae	Passeriformes	3	0	shape	0.33
Zitting Cisticola	<i>Cisticola juncidis</i>	Cisticolidae	Passeriformes	3	0	shape and color	0.39
Graceful Prinia	<i>Prinia gracilis</i>	Cisticolidae	Passeriformes	3	0	shape	0.31
Hooded Crow	<i>Corvus cornix</i>	Corvidae	Passeriformes	4	0	shape	0.27
Yellow-breasted Bunting	<i>Emberiza aureola</i>	Emberizidae	Passeriformes	3	0	shape and color	0.31

Cretzschmar's Bunting	<i>Emberiza caesia</i>	Emberizidae	Passeriformes	3	0	shape and color	0.33
Corn Bunting	<i>Emberiza calandra</i>	Emberizidae	Passeriformes	3	0	shape	0.33
Yellow-browed Bunting	<i>Emberiza chrysophrys</i>	Emberizidae	Passeriformes	3	0	shape and color	0.28
Rock Bunting	<i>Emberiza cia</i>	Emberizidae	Passeriformes	3	0	shape and color	0.25
Yellowhammer	<i>Emberiza citrinella</i>	Emberizidae	Passeriformes	3	0	shape and color	0.32
Ortolan Bunting	<i>Emberiza hortulana</i>	Emberizidae	Passeriformes	3	0	shape and color	0.33
Pine Bunting	<i>Emberiza leucocephalos</i>	Emberizidae	Passeriformes	3	0	shape and color	0.29
Black-headed Bunting	<i>Emberiza melanocephala</i>	Emberizidae	Passeriformes	3	0	shape	0.33
Little Bunting	<i>Emberiza pusilla</i>	Emberizidae	Passeriformes	3	0	shape and color	0.34
Common Reed Bunting	<i>Emberiza schoeniclus</i>	Emberizidae	Passeriformes	3	0	shape and color	0.24
Black-faced Bunting	<i>Emberiza spodocephala</i>	Emberizidae	Passeriformes	3	0	shape and color	0.25
Striolated Bunting	<i>Emberiza striolata</i>	Emberizidae	Passeriformes	3	0	shape	0.26
Indian Silverbill	<i>Euodice malabarica</i>	Estrildidae	Passeriformes	3	0	shape	0.40
Trumpeter Finch	<i>Bucanetes githagineus</i>	Fringillidae	Passeriformes	3	0	shape	0.27
European Goldfinch	<i>Carduelis carduelis</i>	Fringillidae	Passeriformes	3	0	shape and color	0.24
Common Rosefinch	<i>Carpodacus erythrinus</i>	Fringillidae	Passeriformes	3	0	shape	0.28
Sinai Rosefinch	<i>Carpodacus synoicus</i>	Fringillidae	Passeriformes	3	0	shape	0.23
European Greenfinch	<i>Chloris chloris</i>	Fringillidae	Passeriformes	3	0	shape and color	0.28
Hawfinch	<i>Coccothraustes coccothraustes</i>	Fringillidae	Passeriformes	3	0	shape and color	0.24
Common Chaffinch	<i>Fringilla coelebs</i>	Fringillidae	Passeriformes	3	0	shape and color	0.22
Brambling	<i>Fringilla montifringilla</i>	Fringillidae	Passeriformes	3	0	shape and color	0.27
Common Linnet	<i>Linaria cannabina</i>	Fringillidae	Passeriformes	3	0	shape and color	0.31
Two-barred Crossbill	<i>Loxia leucoptera</i>	Fringillidae	Passeriformes	3	0	shape and color	0.20
Pine Grosbeak	<i>Pinicola enucleator</i>	Fringillidae	Passeriformes	3	0	shape and color	0.25
Crimson-winged Finch	<i>Rhodopechys sanguineus</i>	Fringillidae	Passeriformes	3	0	shape and color	0.27
Desert Finch	<i>Rhodospiza obsoleta</i>	Fringillidae	Passeriformes	3	0	shape and color	0.31
Red-fronted Serin	<i>Serinus pusillus</i>	Fringillidae	Passeriformes	3	0	shape and color	0.17
European Serin	<i>Serinus serinus</i>	Fringillidae	Passeriformes	3	0	shape and color	0.22
Syrian Serin	<i>Serinus syriacus</i>	Fringillidae	Passeriformes	3	0	shape and color	0.24
Eurasian Siskin	<i>Spinus spinus</i>	Fringillidae	Passeriformes	3	0	shape	0.26
Red-rumped Swallow	<i>Cecropis daurica</i>	Hirundinidae	Passeriformes	3	0	shape	0.22
Western House Martin	<i>Delichon urbicum</i>	Hirundinidae	Passeriformes	3	0	shape	0.26
Barn Swallow	<i>Hirundo rustica</i>	Hirundinidae	Passeriformes	3	0	shape	0.28
Rock Martin	<i>Ptyonoprogne fuligula</i>	Hirundinidae	Passeriformes	3	0	shape	0.22
Sand Martin	<i>Riparia riparia</i>	Hirundinidae	Passeriformes	3	0	shape	0.20
Hypocolius	<i>Hypocolius ampelinus</i>	Hypocoliidae	Passeriformes	3	0	shape	0.32
Red-backed Shrike	<i>Lanius collurio</i>	Laniidae	Passeriformes	3	0	shape	0.37
Brown Shrike	<i>Lanius cristatus</i>	Laniidae	Passeriformes	3	0	shape	0.39
Isabelline Shrike	<i>Lanius isabellinus</i>	Laniidae	Passeriformes	3	0	shape	0.30
Lesser Grey Shrike	<i>Lanius minor</i>	Laniidae	Passeriformes	3	0	shape	0.36
Masked Shrike	<i>Lanius nubicus</i>	Laniidae	Passeriformes	3	0	shape	0.36

Turkestan Shrike	<i>Lanius phoenicuroides</i>	Laniidae	Passeriformes	3	0	shape	0.37
Woodchat Shrike	<i>Lanius senator</i>	Laniidae	Passeriformes	3	0	shape	0.25
Arabian Babbler	<i>Argya squamiceps</i>	Leiothrichidae	Passeriformes	3	0	shape	0.27
Pallas's Grasshopper Warbler	<i>Helopsaltes certhiola</i>	Locustellidae	Passeriformes	3	0	shape	0.43
Baikal Bush Warbler	<i>Locustella davidi</i>	Locustellidae	Passeriformes	3	0	shape	0.33
River Warbler	<i>Locustella fluviatilis</i>	Locustellidae	Passeriformes	3	0	shape	0.34
Lanceolated Warbler	<i>Locustella lanceolata</i>	Locustellidae	Passeriformes	3	0	shape and color	0.33
Savi's Warbler	<i>Locustella luscinioides</i>	Locustellidae	Passeriformes	3	0	shape	0.41
Common Grasshopper Warbler	<i>Locustella naevia</i>	Locustellidae	Passeriformes	3	0	shape	0.35
Chinese Bush Warbler	<i>Locustella tacsanowskia</i>	Locustellidae	Passeriformes	3	0	shape	0.33
Tawny Pipit	<i>Anthus campestris</i>	Motacillidae	Passeriformes	3	0	shape and color	0.26
Red-throated Pipit	<i>Anthus cervinus</i>	Motacillidae	Passeriformes	3	0	shape and color	0.33
Olive-backed Pipit	<i>Anthus hodgsoni</i>	Motacillidae	Passeriformes	3	0	shape and color	0.32
Meadow Pipit	<i>Anthus pratensis</i>	Motacillidae	Passeriformes	3	0	shape and color	0.28
Richard's Pipit	<i>Anthus richardi</i>	Motacillidae	Passeriformes	3	0	shape	0.27
Buff-bellied Pipit	<i>Anthus rubescens</i>	Motacillidae	Passeriformes	3	0	shape and color	0.27
Long-billed Pipit	<i>Anthus similis</i>	Motacillidae	Passeriformes	3	0	shape	0.34
Water Pipit	<i>Anthus spinoletta</i>	Motacillidae	Passeriformes	3	0	shape and color	0.33
Tree Pipit	<i>Anthus trivialis</i>	Motacillidae	Passeriformes	3	0	shape and color	0.29
White Wagtail	<i>Motacilla alba</i>	Motacillidae	Passeriformes	3	0	shape and color	0.37
Grey Wagtail	<i>Motacilla cinerea</i>	Motacillidae	Passeriformes	3	0	shape and color	0.37
Citrine Wagtail	<i>Motacilla citreola</i>	Motacillidae	Passeriformes	3	0	shape and color	0.27
Western Yellow Wagtail	<i>Motacilla flava</i>	Motacillidae	Passeriformes	3	0	shape and color	0.38
Eastern Yellow Wagtail	<i>Motacilla tschutschensis</i>	Motacillidae	Passeriformes	3	0	shape and color	0.45
Siberian Rubythroat	<i>Calliope calliope</i>	Muscicapidae	Passeriformes	3	0	shape	0.25
Rufous-tailed Scrub Robin	<i>Cercotrichas galactotes</i>	Muscicapidae	Passeriformes	3	0	shape and color	0.20
Black Scrub Robin	<i>Cercotrichas podobe</i>	Muscicapidae	Passeriformes	3	0	shape and color	0.30
European Robin	<i>Erithacus rubecula</i>	Muscicapidae	Passeriformes	3	0	shape	0.33
Taiga Flycatcher	<i>Ficedula albicilla</i>	Muscicapidae	Passeriformes	3	0	shape and color	0.28
Collared Flycatcher	<i>Ficedula albicollis</i>	Muscicapidae	Passeriformes	3	0	shape and color	0.30
European Pied Flycatcher	<i>Ficedula hypoleuca</i>	Muscicapidae	Passeriformes	3	0	shape and color	0.23
Red-breasted Flycatcher	<i>Ficedula parva</i>	Muscicapidae	Passeriformes	3	0	shape	0.23
Semicollared Flycatcher	<i>Ficedula semitorquata</i>	Muscicapidae	Passeriformes	3	0	shape and color	0.27
Yellow-rumped Flycatcher	<i>Ficedula zanthopygia</i>	Muscicapidae	Passeriformes	3	0	shape	0.29
White-throated Robin	<i>Irania gutturalis</i>	Muscicapidae	Passeriformes	3	0	shape	0.37
Siberian Blue Robin	<i>Larvivora cyane</i>	Muscicapidae	Passeriformes	3	0	shape	0.28
Thrush Nightingale	<i>Luscinia luscinia</i>	Muscicapidae	Passeriformes	3	0	shape	0.31
Common Nightingale	<i>Luscinia megarhynchos</i>	Muscicapidae	Passeriformes	3	0	shape	0.30
Bluethroat	<i>Luscinia svecica</i>	Muscicapidae	Passeriformes	3	0	shape	0.32
Common Rock Thrush	<i>Monticola saxatilis</i>	Muscicapidae	Passeriformes	3	0	shape	0.27
Blue Rock Thrush	<i>Monticola solitarius</i>	Muscicapidae	Passeriformes	3	0	shape	0.28

Asian Brown Flycatcher	<i>Muscicapa dauurica</i>	Muscicapidae	Passeriformes	3	0	shape	0.25
Spotted Flycatcher	<i>Muscicapa striata</i>	Muscicapidae	Passeriformes	3	0	shape	0.19
Persian Wheatear	<i>Oenanthe chrysopygia</i>	Muscicapidae	Passeriformes	3	0	shape	0.27
Cyprus Wheatear	<i>Oenanthe cypriaca</i>	Muscicapidae	Passeriformes	3	0	shape	0.25
Desert Wheatear	<i>Oenanthe deserti</i>	Muscicapidae	Passeriformes	3	0	shape and color	0.31
Finsch's Wheatear	<i>Oenanthe finschii</i>	Muscicapidae	Passeriformes	3	0	shape	0.23
Isabelline Wheatear	<i>Oenanthe isabellina</i>	Muscicapidae	Passeriformes	3	0	shape	0.27
White-crowned Wheatear	<i>Oenanthe leucopyga</i>	Muscicapidae	Passeriformes	3	0	shape	0.25
Mourning Wheatear	<i>Oenanthe lugens</i>	Muscicapidae	Passeriformes	3	0	shape	0.29
Eastern Black-eared Wheatear	<i>Oenanthe melanoleuca</i>	Muscicapidae	Passeriformes	3	0	shape	0.35
Blackstart	<i>Oenanthe melanura</i>	Muscicapidae	Passeriformes	3	0	shape	0.31
Hooded Wheatear	<i>Oenanthe monacha</i>	Muscicapidae	Passeriformes	3	0	shape and color	0.33
Northern Wheatear	<i>Oenanthe oenanthe</i>	Muscicapidae	Passeriformes	3	0	shape	0.31
Pied Wheatear	<i>Oenanthe pleschanka</i>	Muscicapidae	Passeriformes	3	0	shape	0.27
Kurdish Wheatear	<i>Oenanthe xanthopyrna</i>	Muscicapidae	Passeriformes	3	0	shape	0.23
Daurian Redstart	<i>Phoenicurus aureus</i>	Muscicapidae	Passeriformes	3	0	shape	0.20
Black Redstart	<i>Phoenicurus ochruros</i>	Muscicapidae	Passeriformes	3	0	shape	0.26
Common Redstart	<i>Phoenicurus phoenicurus</i>	Muscicapidae	Passeriformes	3	0	shape	0.27
Pied Bushchat	<i>Saxicola caprata</i>	Muscicapidae	Passeriformes	3	0	shape	0.28
Whinchat	<i>Saxicola rubetra</i>	Muscicapidae	Passeriformes	3	0	shape	0.28
European Stonechat	<i>Saxicola rubicola</i>	Muscicapidae	Passeriformes	3	0	shape	0.24
Amur Stonechat	<i>Saxicola stejnegeri</i>	Muscicapidae	Passeriformes	3	0	shape and color	0.25
Red-flanked Bluetail	<i>Tarsiger cyanurus</i>	Muscicapidae	Passeriformes	3	0	shape	0.24
Palestine Sunbird	<i>Cinnyris osea</i>	Nectariniidae	Passeriformes	3	0	shape and color	0.23
Eurasian Golden Oriole	<i>Oriolus oriolus</i>	Oriolidae	Passeriformes	4	0	shape and color	0.37
Crested Tit	<i>Lophophanes cristatus</i>	Paridae	Passeriformes	3	0	shape	0.22
Great Tit	<i>Parus major</i>	Paridae	Passeriformes	3	0	shape	0.23
Coal Tit	<i>Pariparus ater</i>	Paridae	Passeriformes	3	0	shape	0.24
Siberian Tit	<i>Poecile cinctus</i>	Paridae	Passeriformes	3	0	shape	0.24
Sombre Tit	<i>Poecile lugubris</i>	Paridae	Passeriformes	3	0	shape	0.22
Willow Tit	<i>Poecile montanus</i>	Paridae	Passeriformes	3	0	shape	0.22
Pale Rockfinch	<i>Carpospiza brachydactyla</i>	Passeridae	Passeriformes	3	0	shape	0.29
Spanish Sparrow	<i>Passer hispaniolensis</i>	Passeridae	Passeriformes	3	0	shape	0.36
Dead Sea Sparrow	<i>Passer moabiticus</i>	Passeridae	Passeriformes	3	0	shape	0.35
Rock Sparrow	<i>Petronia petronia</i>	Passeridae	Passeriformes	3	0	shape	0.29
Arctic Warbler	<i>Phylloscopus borealis</i>	Phylloscopidae	Passeriformes	3	0	shape	0.28
Common Chiffchaff	<i>Phylloscopus collybita</i>	Phylloscopidae	Passeriformes	3	0	shape	0.28
Dusky Warbler	<i>Phylloscopus fuscatus</i>	Phylloscopidae	Passeriformes	3	0	shape	0.26
Yellow-browed Warbler	<i>Phylloscopus inornatus</i>	Phylloscopidae	Passeriformes	3	0	shape and color	0.25
Eastern Bonelli's Warbler	<i>Phylloscopus orientalis</i>	Phylloscopidae	Passeriformes	3	0	shape	0.18

Two-barred Warbler	<i>Phylloscopus plumbeitarsus</i>	Phylloscopidae	Passeriformes	3	0	shape	0.24
Radde's Warbler	<i>Phylloscopus schwarzi</i>	Phylloscopidae	Passeriformes	3	0	shape	0.26
Wood Warbler	<i>Phylloscopus sibilatrix</i>	Phylloscopidae	Passeriformes	3	0	shape	0.28
Willow Warbler	<i>Phylloscopus trochilus</i>	Phylloscopidae	Passeriformes	3	0	shape	0.27
Dunnock	<i>Prunella modularis</i>	Prunellidae	Passeriformes	3	0	shape	0.23
Radde's Accentor	<i>Prunella ocularis</i>	Prunellidae	Passeriformes	3	0	shape	0.31
White-spectacled Bulbul	<i>Pycnonotus xanthopygos</i>	Pycnonotidae	Passeriformes	3	0	shape	0.33
White-crowned Penduline Tit	<i>Remiz coronatus</i>	Remizidae	Passeriformes	3	0	shape and color	0.29
Eurasian Penduline Tit	<i>Remiz pendulinus</i>	Remizidae	Passeriformes	3	0	shape and color	0.25
Cetti's Warbler	<i>Cettia cetti</i>	Scotocercidae	Passeriformes	3	0	shape	0.27
Scrub Warbler	<i>Scotocerca inquieta</i>	Scotocercidae	Passeriformes	3	0	shape	0.33
Eurasian Nuthatch	<i>Sitta europaea</i>	Sittidae	Passeriformes	3	0	shape	0.24
Western Rock Nuthatch	<i>Sitta neumayer</i>	Sittidae	Passeriformes	3	0	shape	0.21
Tristram's Starling	<i>Onychognathus tristramii</i>	Sturnidae	Passeriformes	3	0	shape	0.26
Common Starling	<i>Sturnus vulgaris</i>	Sturnidae	Passeriformes	3	0	shape	0.32
Eastern Subalpine Warbler	<i>Curruca cantillans</i>	Sylviidae	Passeriformes	3	0	shape	0.24
Common Whitethroat	<i>Curruca communis</i>	Sylviidae	Passeriformes	3	0	shape	0.32
Spectacled Warbler	<i>Curruca conspicillata</i>	Sylviidae	Passeriformes	3	0	shape	0.30
Eastern Orphean Warbler	<i>Curruca crassirostris</i>	Sylviidae	Passeriformes	3	0	shape	0.36
Lesser Whitethroat	<i>Curruca curruca</i>	Sylviidae	Passeriformes	3	0	shape	0.26
Arabian Warbler	<i>Curruca leucomelaena</i>	Sylviidae	Passeriformes	3	0	shape	0.25
Sardinian Warbler	<i>Curruca melanocephala</i>	Sylviidae	Passeriformes	3	0	shape	0.28
Cyprus Warbler	<i>Curruca melanothorax</i>	Sylviidae	Passeriformes	3	0	shape and color	0.27
Asian Desert Warbler	<i>Curruca nana</i>	Sylviidae	Passeriformes	3	0	shape and color	0.22
Barred Warbler	<i>Curruca nisoria</i>	Sylviidae	Passeriformes	3	0	shape	0.29
Rüppell's Warbler	<i>Curruca ruppeli</i>	Sylviidae	Passeriformes	3	0	shape	0.28
Eurasian Blackcap	<i>Sylvia atricapilla</i>	Sylviidae	Passeriformes	3	0	shape	0.26
Garden Warbler	<i>Sylvia borin</i>	Sylviidae	Passeriformes	3	0	shape	0.28
Eurasian Wren	<i>Troglodytes troglodytes</i>	Troglodytidae	Passeriformes	3	0	shape	0.18
Redwing	<i>Turdus iliacus</i>	Turdidae	Passeriformes	3	0	shape	0.23
Song Thrush	<i>Turdus philomelos</i>	Turdidae	Passeriformes	3	0	shape	0.28
Grey Heron	<i>Ardea cinerea</i>	Ardeidae	Pelecaniformes	5	6	shape	0.21
Brown Pelican	<i>Pelecanus occidentalis</i>	Pelecanidae	Pelecaniformes	4	10	shape	0.34
Eurasian Wryneck	<i>Jynx torquilla</i>	Picidae	Piciformes	4	0	shape and color	0.45
Great Crested Grebe	<i>Podiceps cristatus</i>	Podicipedidae	Podicipediformes	6	6	shape and color	0.50
Sooty Shearwater	<i>Ardenna grisea</i>	Procellariidae	Procellariiformes	4	8	shape	0.42
Short-eared Owl	<i>Asio flammeus</i>	Strigidae	Strigiformes	3	0	shape and color	0.20
Pharaoh Eagle Owl	<i>Bubo ascalaphus</i>	Strigidae	Strigiformes	3	0	shape and color	0.16
Eastern Screech-Owl	<i>Megascops asio</i>	Strigidae	Strigiformes	3	0	shape and color	0.18
Tawny Owl	<i>Strix aluco</i>	Strigidae	Strigiformes	3	0	shape and color	0.27
Barn Owl	<i>Tyto alba</i>	Tytonidae	Strigiformes	3	0	shape and color	0.16
Northern Gannet	<i>Morus bassanus</i>	Sulidae	Suliformes	3	12	shape	0.45

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