Elucidating the evolution of the parrot vocal organ and links to bioacoustic traits

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Vocal organ, syrinx, morphology and vocal capabilities within and across bird species is extraordinary. Most birds have only extrinsic muscles of the syrinx and two sound sources that produce F0, or the fundamental frequency. However, Parrots (Psittaciformes) have evolved a syrinx with intrinsic muscles and only one sound source. Intrinsic muscles have been proposed to be necessary for the development of large vocabularies as well as affecting fundamental frequency range. Psittaciformes and most songbird (Passeriformes) species have intrinsic muscles in their syrinx, but Passeriformes retain two sound sources. The sister taxa of Psittaciformes, Falcons (Falconiformes), only have extrinsic muscles and are not known to be capable of complex vocalizations. Psittaciformes and Passeriformes have a richer species diversity and are more social than Falconiformes. While there have been some studies on select Psittaciformes and Passeriformes species that examine the complex vocal capabilities and morphology of the syrinx, there have been no comparative studies of the morphology and acoustic parameters across these three groups in the Eufalconimorphae (Falconiformes, Passeriformes, and Psittaciformes).

This study adds insight into the evolution of syrinx morphology among Eufalconimorphae and its potential effects on the scaling relationships between F0 and body mass in Psittaciformes and Falconiformes. Diffusible iodine-based contrast-enhanced computed tomography (diceCT) was used to visualize the syrinx morphology of three Psittaciformes and one falconiform. Morphological descriptions from prior literature were used to compare two additional early diverging and well nested Passeriformes, and two early-diverging Psittaciformes (Strigipoidea). I assessed the mean, the minimum, and the maximum fundamental frequency of 70 Psittaciform species and 34 falconiform species sourced from Xenocanto.org, and compared the relationship of F0 (Min, Max, Mean) to body mass using phylogenetic generalized least squares (PGLS) regressions for Psittaciformes and Falconiformes. The negative allometric relationship between F0 and body mass was significant in all Psittaciformes and Falconiformes examined in this study. Maximum F0 was recovered as the acoustic parameter that is the least constrained by body size in Psittaciformes, and the most constrained by body size in Falconiformes. Psittaciformes show more variance than Falconiformes in all measures of F0. This observed difference could be attributable to presence of intrinsic muscles or the transition from two sound sources to one. We find a well-mineralized tracheal shield, which is connected to the bronchial edge of the lateral tympaniform membrane, to be an evolutionary innovation within Psittaciformes. Previously unreported sexual dimorphism was seen in the parrot species, *Aratinga holochlora*, with the male showing a slightly larger intrinsic muscle (*m.syringealis profundus;SP*) than the female. We also find some evidence that a novel intrinsic muscle in Psittaciformes (m.*syringealis profundus;SP*) shows a similar function to an extrinsic muscle (*m. tracheolateralis; TL*) in Falconiformes and basally-divergent Passeriformes. The position of this intrinsic muscle and relationship with fibers of the TL may suggest a shared ontogeny but this needs to be investigated further.

New data is presented here on the evolution of the structure of the syrinx in Eufalconimorphae. We hypothesize from these results that the presence of intrinsic muscles,

linked to a single sound source in the parrot syrinx, directly impact maximum F0 and potentially influence the acquisition of their complex vocal capabilities. Additional functional studies are needed to further investigate this hypothesis. Nonetheless, these data may inform specific traits of the fossilizable cartilaginous rings that can indicate the timing of acquisition of these traits in parrots and add to our understanding of the evolution of avian vocalization more generally.

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