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"Assessing the macroevolutionary consequences of phenotypic integration with dense phenomic data from living and extinct tetrapods"

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Phenotypic integration is a pervasive characteristic of organisms. Interactions among morphological traits, termed phenotypic integration, can be readily identified through quantitative analysis of geometric morphometric data from living and extinct organisms. These interactions have been hypothesized to reflect genetic, developmental, and functional relationships and to be a fundamental influence on morphological evolution on small to large time scales. Simulations using covariance matrices derived from landmark data for diverse vertebrate taxa confirm that trait integration can influence the trajectory and magnitude of response to selection. At a macroevolutionary scale, high phenotypic integration produces both more and less disparate organisms, and most often the latter, than would be expected under unconstrained evolution, thereby increasing morphological range, but also homoplasy and convergence. However, this effect may not translate simply to evolutionary rates.

Here, I will discuss the macroevolutionary consequences of phenotypic integration for cranial evolution through deep time in tetrapods. While most large-scale studies of phenotypic integration and morphological evolution utilise relatively limited descriptors of morphology, such as lengths or a small set of homologous landmarks, surface sliding semi-landmark analysis allows for detailed quantification of complex 3D shapes, even across highly disparate taxa. We conducted the largest analysis to date of morphological evolution across diverse tetrapod clades using a dense dataset of landmarks and sliding semi-landmarks spanning the entire cranium and nearly 300 million years of evolution. Crania are highly modular, but this pattern varies across tetrapods. Modules also have disparate magnitudes of trait integration, which reflect developmental complexity in some, but not all clades. Tempo and mode are similarly highly variable, with some modules, such as the basicranium of birds, showing early bursts of shape evolution, while other regions, such as the rostrum, show sustained change throughout clade evolution. Leveraging this high density morphometric data, we further demonstrate that variation is unequally distributed across the cranium and that distinct patterns of variation characterize different tetrapod clades.

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