Supplementary Materials and Methods

Glossary definition

Relative brain size (referred to as brain size hereafter) is defined as brain volume relative to body mass (Ksepka et al., 2020). Encephalization refers to an increase in brain size (Lefebvre, 2002). Clutch size is defined as the number of eggs laid in a single brood by a breeding pair of birds (Niehoff, 2007). Prehatching maternal investment (PMI) refers to maternal energy investment before hatching for each offspring without considering time costs in a breeding season, proxied by egg mass (Kilpimaa et al., 2007; Mäenpää & Smiseth, 2017). Total PMI (TPMI) refers to total maternal energy investment before hatching without considering time costs in a breeding season, proxied by egg mass×clutch size. Reproductive success is defined as at least one chick successfully fledging in a breeding season for a breeding pair (Nur & Sydeman, 1999). Brood mortality is defined as no chicks fledging successfully in a breeding season for a breeding pair (Martin, 2014).

Data collection

Raw brain size data of birds were collected from two recently published datasets (Dante et al., 2020; Ksepka et al., 2020). Raw egg mass and clutch size data were obtained from previous studies (Jetz et al., 2008; Minias & Włodarczyk, 2020; Stoddard et al., 2017). Raw life history data (hatching and fledging times) were obtained from Dante et al. (2020). Based on data assembly, we generated a dataset of 1 214 extant bird species of Neognathae (Neoaves and Galloanseres), covering 42 orders and 186 families. Among them, 22 orders and 31 families contain more than five species.

Measurement of correlation between brain size and TPMI, PMI, and clutch size

Here, we used species brain size as a proxy for female brain size of the species. This was because: 1) the current database of female brain size is limited to only a few species (n=39) (Garamszegi et al., 2005); and 2) the difference in brain size between species is more significant than that between the sexes of the same species (Garamszegi et al., 2005).

We used phylogenetic generalized least squares (pGLS) analyses to estimate the correlation between brain size (log-transformed, independent variable) and TPMI (log-transformed, dependent variable) within a breeding season using all collected bird data, thereby obtaining the slope (R^2) and corresponding P-value. The slope measured the change in brain size in response to a change in TPMI. To determine whether changes in TPMI were due to changes in PMI or clutch size, we estimated the correlations between brain size and PMI and between brain size and clutch size separately. To generalize our findings, we measured the correlations between brain size and TPMI, PMI, and clutch size within each order. Orders with fewer than five species in the dataset were excluded from analysis (Ksepka et al., 2020).

To determine whether changes in TPMI in female bird species with different brain sizes affect parental time costs, we measured the correlations between TPMI and parenting time. Parental care mainly involves two stages (i.e., hatching and fledging periods) (Cooney et al., 2020). Therefore, we analyzed parental time costs in reproduction based on these two stages. Using all collected data, we estimated the correlations between TPMI and hatching and fledging time, controlling for phylogeny.

Identification of shifts in brain size-TPMI slope

To understand how the TPMI allocation strategy evolved with increasing brain size over avian evolutionary history, we identified shifts in the brain size-TPMI slope across bird phylogeny (Jarvis et al., 2014; Prum et al., 2015) by comparing the slope of each order with its ancestral slope. We used the phylogenic tree of Jarvis et al. (2014) as a backbone because the tree was constructed based on whole-genome data. Species not in Jarvis et al. (2014) were positioned in reference to the tree reconstructed by Prum et al. (2015). Analyses were conducted at the order level. We considered a shift to be significant if the 95% confidence interval (CI) of its slope did not overlap with the 95% CI of its ancestral slope. For example, Psittaciformes had a slope of -1.23 with a 95% CI (-1.37, -1.09), while its ancestral slope was -0.89 with a 95% CI (-1.09, -0.69). As the 95% CIs of the two slopes did not overlap, this indicated a significant shift. In addition, a shift was considered 'higher' if the slope of a studied order was more negative than its ancestral slope (e.g., -1.23 in Psittaciformes vs. -0.89 in its ancestral slope). Otherwise, it was considered a lower shift.

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