**Introduction**

All things in the universe are experiencing evolutionary changes. Living things must adapt through forces such as natural selection, allowing favorable traits that are heritable to be passed on to offspring. This passing on of heritable traits that are favorable allows the offspring to be better competitors in their environments.

The biodiversity of life on Earth can be linked to organisms’ adaptations to the ever-changing environment. Across evolutionary time organisms have adapted to various geographical and climate changes, and they must do this to ‘win the evolutionary game’; you either adapt and perform better than your competitors or you die (Sagarin 2003). Organisms can vary in traits such as their color, speed, size of their body, size of appendages, mating calls, aggressiveness, and many other things. Variation and the ability to vary between and within species are important for factors such as selective forces and drift to work. This allows advantageous traits to be passed through generations allowing the organisms to better hunt, better mate, and to better survive (Darling 2014).

An example of this can be seen in avian species, as they branched off the phylogenic tree from their reptile ancestor. Avians faced new challenges leading them to become their own species. During this branching, the avian species evolved things such as wings for flight and alongside flight, they adapted new ways to get food due to their loss of ability to use their forearms/claws to gather food. Birds gained beaks that come in diverse shapes and sizes to now capture and gather their food. Their adaptations of the ability to travel long distances through flight lead to the need to alter their facial structures to allow for a lightweight, yet effective feeding mechanism (Wu et al. 2006). Through time both the beaks and wings of birds have evolved through selection, allowing them to better migrate, find food sources better, escape from predators, and live an easier lifestyle that better fits in with their ecosystem.

Flying in birds can be energetically costly, so, it is therefore important that once they reach their destination they be as efficient as possible in their mating and feeding efforts to maximize their overall performance (Vágási et al. 2016). The wingspan of birds is a physical adaptation that impacts how far, fast, and how much energy they use when flying. A longer wingspan helps in the ability to soar and fly through the air as larger wings offer more lift; however, it can be very energetically costly for them to get off the ground, likely meaning once they lift off they will be traveling longer distances but putting in more initial effort. According to the aerodynamic theory, a longer wingspan in birds should mean they are built to fly longer migratory distances (Hahn et al. 2015). With that, due to the energetic cost of traveling long distances, it is likely that birds with longer wingspans will likely have adapted features that make their feeding and mating efforts less costly. Flying takes a lot of power from the bird’s circulatory system to help keep the birds in the air. Having a larger beak allows the birds to have better air circulating mechanisms, helping them regulate their body temperature during longer flights as their beaks are highly vascularized (Contemporary VCE Biology. 2020). The purpose of this study was to see if beak depth and wing chord in millimeters are positively correlated in avian species, which could be of importance for longer flight distance, better hunting abilities, and better heat regulation techniques for long flights in avian species. The data for this study came from a previously published dataset by B.G. Freeman, D. Schluter, and J.A. Tobias published in February 2022, this data has over 1000 different avian species with 5 traits measured for each individual allowing for a diverse array of data to be analyze, however, some of the species in the data had to throw out due to missing information for the traits. The exact reason for the missing traits is unknown, and it is unknown exactly how these missing data points impacted the overall validity of the study, however, due to the abundance of individuals tested it is unlikely this will have a huge impact on the results. I hypothesized that bill depth in millimeters and wing chord in millimeters are positively correlated in avian species.

**Materials and Methods**

*Data Collection*

The data for this study was gathered from a previously published dataset by B.G. Freeman, D. Schluter, and J.A Tobias published in February of 2022 (https://datadryad.org/stash/dataset/doi:10.5061%2Fdryad.j9kd51cbp). To obtain this data a global data set of 1141 sister pairs, where sister pairs were defined from a dated global phylogeny of bird species. This dataset only included species that were placed on the tree due to the basis of genetic data. The study by Freeman et al., used data that was published by (Cooney et al. 2017), where they excluded 141 sister pairs from mixed latitudinal zones, 14 other sister pairs were excluded that had divergences that dated back more than 20 Mya, and another 10 sister pairs were dropped from the dataset where one or more morphological feature had a missing value. These dropped species left the dataset with a total of 1141 avian sister species pairs. The morphological data was gathered from a global dataset where the beak length along the culmen, beak length from nares to tips, beak depth at the nares, beak width at the nares, and wing chord were measured for a total of 5 traits. Individuals with data missing for any of the five traits were excluded from the final dataset (Freeman et al. 2020). A phylogenic tree was generated for this data by entering the names of the species into vertlife.org, this tree was then run into RStudio version 2022.

*Analyzing the Data*

For this study, the data was simplified into a CSV file that included the bird species names, beak depth (mm), and wingspan (mm) and was read into R studios to be analyzed. Species with NA for either beak depth or wingspan were dropped from the phylogeny and the dataset. After the CSV was created the R package phytools were used to read the nexus file for phylogeny.

*Making the Graph*

An x-y scatter plot was generated (x-axis labeled wing, y-axis labeled beak) with a best- fit line. The best fit line for the data was generated using the plot function and abline, which allowed for a positive trend to be shown for the dataset. This graph, plus the best fit line allowed for a general increasing (positive) relationship to be shown for Wingspan and Beak depth graphically.

*Pearson’s Correlation Test*

A Pearson coefficient correlation test was performed in RStudio to see if there was a positive relationship between Wingspan (mm) which was on the x-axis and Beak depth (mm) which was on the y-axis. A Pearson correlation test was used because it measures the linear relationship between continuous variables and assumes a finite variance and covariance (Pearson n.d.). To generate this test the function cov2cor was used which converts the covariance matrix (S) to a correlation matrix fast and effectively.

*Spearman’s Correlation Test*

A Spearman’s correlation test was performed in RStudio to see if a positive relationship existed between the two variables being tested, beak depth (mm) and wing chord (mm). For this test, the function cor was used with the method set to “Spearman”. A Spearman’s test is valuable in determining the direction of the monotonic relationship between the variables tested rather than testing the strength and direction of the relationship between the variables like Pearson does (Raerd Statistics n.d.).

**Results**

Results from the Pearson Correlation test gave a value of 0.6896156 suggesting there was a moderate positive correlation. The R-value for a Pearson Correlation test ranges from -1 to 1 with a value of 0.7 or greater suggesting a strong positive correlation. The graph plotted also shows a general upward trend further supplementing the results from the Pearson’s test. The Spearman Correlation test gave a value of 0.7719603 suggesting there was a strong correlation between the variables tested. Spearman’s correlation values range from -1 to 1, with a value of 0 meaning no correlation. For the best fit line generated by the scatter plot a slope of 0.0518442 was obtained, and an R^2 adjusted value of 0.5157 was obtained, which is adjusted for the number of predictors in the model. A p-value of 2e^-16 was obtained which is within the accepted cutoff of 0.05 or less to be considered statistically significant.



*Figure 1: x-y scatter plot representing the correlation between avian species’ beak depth in mm and wing chord in mm. Each point represents an individual. The best fit line generated gave a slope of 0.0518442, and a p-value of 2e^-16. This graph shows a general positive trend between the two traits.*

**Discussion**

The dataset for this study which was obtained from a previously published dataset by Freedman et al. showed a positive correlation between avian beak depth (mm) and wing chord (mm). The results of both Spearman’s correlation test and Pearson’s correlation test suggested there was a positive correlation between beak depth and wing chord, supporting the initial hypothesis of the study. The Pearson correlation test suggested there was a moderate positive correlation, while the Spearman correlation test suggested there was a strong positive correlation between the two variables tested. The difference between a moderate and strong positive correlation is likely due to the different assumptions made by each test. The p-value of 2e^-16 and the slope of the best fit line generated through the x-y scatter plot implies there is strong evidence that these values aren’t just by chance positively correlated, since a positive correlation is shown through all three-test performed on the data. There are likely some underlying reasons as to why a consistent positive correlation is seen between the two variables, however, to understand the reasoning behind this correlation further testing would need to be completed.

When birds evolved from their reptile ancestors, they had to make many adaptations to allow for flight and mechanisms to gather food due to their loss of forelimbs. As species evolve through mechanisms such as natural selection, they allow for their offspring to better survive and adapt to the everchanging environment. As hypothesized earlier in the paper, it is likely that the birds with bigger wings expend more energy flying and getting ready for liftoff that they have to adapt other features on their body to decrease overall energy use, such as a larger beak that allows them to better hunt and gather food. It is likely that birds with larger wings have a high cardiac output and have adapted larger beaks to help regulate their body temperature and air intake on their long flights. However, it is also possible that birds with longer wing chords also have deeper beak depths because they are just overall larger birds and as the wing size gets larger all of the birds’ features get larger and they have no biologically significant reason for being that way, besides just overall larger size.

To make the results of the study more generalizable a bigger population of birds from around the world could be studied to see if this positive correlation exists between more than just this dataset. A possible limitation of this study is the fact that just one dataset was relied on, and this dataset came from a previously studied dataset, however over 1000 bird sister species were considered for this study so it is unlikely this had a huge impact on the overall assumption made. The previous dataset also threw out sister species that either had missing values or were from 20 Mya +, lowering the number of species tested by a slight amount. Further, our study made the decision to throw out 2 sister species that had NA for either wing chord or beak depth from the dataset that was downloaded from dryad, leading to the possibility of some slight inaccuracy in the results. These species that were thrown out could’ve been the species that would’ve turned what was found to be a positive correlation into a neutral or even negative correlation, however, the minimal species deleted from the dataset is unlikely to have a huge impact on the overall validity of the study due to the abundance of individuals and species values that were calculated for. The reason for the missing data (NA) in the dataset is unknown, so it is uncertain if the missing data points were of great importance to the overall assumptions made through the analysis of the data. Overall, due to the high number of species tested within the analysis (>1000), it is unlikely that a few being thrown out would have any significant impact on the study, however, it would be beneficial to see if a similar positive correlation existed in another subset of avian species, which would allow for further assumptions to be made on the relationship and the significance of the results to the overall bird population. In the near future, further studies should be made to see if there is an evolutionarily significant reason as to why birds with longer wing chords also have deeper beak depths, and how these features help in the hunting and the regulation of the birds’ cardiac and energy expenditure.

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