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Skeletal correlates of body weight in the Black-billed Streamertail (*Trochilus scitulus*) of Jamaica

Gary R. Graves

Department of Vertebrate Zoology, MRC-116, National Museum of Natural History, Smithsonian Institution, P. O. Box 37012, Washington, D.C. 20013-7012, U.S.A.

Abstract.—Analyses of body size evolution in hummingbirds (Trochilidae) are hampered by the lack of standardized weight data for most of the ~330 described species. Moreover, little is known of the morphological correlates of body weight upon which a body-size index could be constructed. I investigated the skeletal correlates of body weight in the endemic Black-billed Streamertail (*Trochilus scitulus*) of Jamaica. Mist-netted males were weighed at initial capture and after the holding period (2.1–6.7 hr). Seven of 10 skeletal characters exhibited marginally higher correlations with the second measure of body weight, which was unbiased by gut contents. Sternum length emerged as the single best skeletal predictor of body weight. A multivariate index (PCA 1) derived from three sternal characters had approximately the same predictive value as a comparable analysis of all ten skeletal characters. This suggests that a simple multivariate measure of sternal morphology may provide a reliable body size index for hummingbirds.

Keywords.—Body size index, hummingbirds, museum specimens, Trochilidae, *Trochilus scitulus*.

Introduction

Early naturalists were astonished by the minuscule size, hovering flight, and jewel-like plumage of hummingbirds (Grew 1693), but who then could have guessed that the mechanics of hummingbird flight (Chai and Millard 1997; Altshuler et al. 2004; Warrick et al. 2005) and the physiological consequences of small body size (Calder 1974) would be hot research topics three centuries later? Comparative analyses of hummingbirds (Trochilidae) make frequent reference to interspecific variation in body size (Feinsinger and Chaplin 1975; Feinsinger et al. 1979; Colwell 2000; Stiles et al. 2005), yet rigorously standardized weight data exist for only a small fraction of the ~330 species of hummingbirds. An additional obstacle to comparative analyses is posed by our poor understanding of the morphological correlates of body weight. Consequently, it is uncertain which external or skeletal variables obtained from museum specimens may serve as useful surrogates for body weight.

This paper focuses on the skeletal correlates of body weight in the Black-billed Streamertail (*Trochilus scitulus*), restricted to the eastern tip of Jamaica in Portland and St. Thomas parishes. It is replaced by the Red-billed Streamertail (*T. polytmus*) in the remainder of the forested areas of the island except for districts along the southern coast that experience a prolonged dry season. A narrow zone of hybridization occurs where the two distinctive phenotypes meet in the Rio Grande Valley (Gill et al. 1973; MacColl and Lewis 2000). Male hybrids are distinguished by intermediate bill color (Gill et al. 1973; Graves 2009) but the taxonomic and evolutionary status of *polytmus* and *scitulus* is still unresolved. Gill et al. (1973) treated them as subspecific entities (AOU 1998) but (Schuchmann 1978, 1980) noted differences in song and courtship display which suggest that *polytmus* and *scitulus* represent reproductively isolated species—a treatment I follow here.

Ongoing studies of hybridization provided the opportunity to examine the statistical relationship between body weight and the size of skeletal characters in *Trochilus scitulus*. I addressed two questions: (*i*) Which skeletal characters correlate most highly with body weight? (*ii*) Do multivariate indices of skeletal size have superior predictive power? Finally, I address the use of body weight data obtained from museum specimens in comparative studies of hummingbirds.

Methods

Body weight (Lidicker 2008) of hummingbirds fluctuates during the daily cycle primarily because of variation in gut contents. Daily highs are attained in late afternoon before roosting and low points are recorded immediately before departure from roosts in the morning (Calder et al. 1990). Crop and gut contents can add up to 34 % to the body weight of hummingbirds (Calder et al. 1990). However, passage rates of fluids through the gut is rapid, and contents are excreted within 30 minutes of ingestion (Karasov et al. 1986; Tiebout 1989). Thus, the time of capture and the duration between the capture and weighing of individuals can have a significant effect on the estimation of body weight.

Streamertails reported in this study were mist-netted at least 90 minutes after sunrise between 31 October and 20 February (2003-2005). Analyses were limited to males in basic plumage (n = 22) which exhibited adult bill color (Graves 2009). Body weight (± 0.005 g) was measured immediately after capture (1st measurement) with digital scales (AND® PV-60). Netted streamertails were placed individually in soft cotton muslin bags which were suspended in heavily shaded locations with good air circulation. Weight was measured a second time after the birds were euthanized. Holding time was defined as the interval between the two measurements. Specimens were prepared as rounded skins and partial skeletons (lacking rostrum), which are deposited in the research collections of the National Museum of Natural History (USNM), Smithsonian Institution. Fat was scored as (1) light or minimal along feather tracts and little or no furcular fat; (2) moderate amounts of fat along feather tracts and in furcular cleft; or (3) extensive deposits in furcular cleft and along feather tracts. Skeletal elements were measured with digital calipers to the nearest 0.01 mm under a 10 × stereo microscope: (*i*) skull width; (*ii*) coracoid length; (*iii*) humerus length; (*iv*) humerus proximal head width; (*v*) femur length; (*vi*) tibiotarsus length; (*vii*) tarsometatarsus length; (*viii*) sternum length; (*ix*) keel length; and (*x*) keel depth.

I used Pearson correlation coefficients to evaluate the correlation between body weight and morphological variables. Differences in character means were evaluated with 2-sample t-tests (separate variance). Wilcoxon signed-rank test was used to compare the relative strength of correlations between the two measures of body weight and skeletal characters. I used principal components analysis (PCA) of correlation matrices extracted from untransformed skeletal variables to generate two indices of body size (Table 1). The first analysis included all 10 skeletal elements whereas the second was restricted to the three sternal measurements (sternum length, keel length, and keel depth). The sternum supports the principal flight muscles (pectoralis and supracoracoideus), which compose as much as 33 % of the lean body weight in hummingbirds (Hartman 1961).

Results

Skeletal characters and body weights of males in first basic (n = 12) and definitive basic plumages (n = 10) were indistinguishable (t-tests, all $P > 0.30$). Accordingly, males of both age classes were pooled in the remaining analyses. Males averaged 5.06 g (± 0.29 g) at capture and 4.71 g (± 0.25 g) after the holding period (2.1–6.7 hr; $\bar{x} = 4.3 \pm 1.3$ hr), a loss

Table 1. Component loadings for PCA 1 from principal components analyses of skeletal characters of *Trochilus scitulus* (Black-billed Streamertail).

Variable	All skeletal characters	Sternum only
Skull width	0.65	
Coracoid length	0.82	
Humerus length	0.87	
Humerus head width	0.54	
Femur length	0.78	
Tibiotarsus length	0.74	
Tarsometatarsus length	0.65	
Sternum length	0.84	0.93
Keel length	0.77	0.89
Keel depth	0.70	0.85
Percent variance explained	54.9 %	79.1 %

equivalent to 3.1–11.1 % ($\bar{x}$ = 7.0 ± 2.1%) of their body weight. Body weight at capture and after holding were highly correlated (n = 22; R^2 = 0.84, t = 10.24, P < 0.0001). Postmortem examination revealed low fat scores ($\bar{x}$ = 1.11) and empty intestinal tracts.

Seven of 10 skeletal characters were significantly correlated with body weight at capture and after the holding period (Table 2). Sternum length emerged as the single best predictor of body weight, followed by humerus length, keel length, and femur length. Skeletal variables were more highly correlated with the second weight measurement (Wilcoxon signed-rank test, z = 1.95, P=0.05). Component loadings for PCA 1 were strongly positive for all variables in both analyses (Table 1), indicating that PCA 1 may serve as a general index of skeletal size. Both measures of body weight were significantly correlated with PCA 1 values (Table 2). The multivariate index (PCA 1) derived from the three sternal characters had roughly the same predictive value as a comparable analysis of all skeletal characters. This suggests that a simple multivariate measure of sternal morphology may have some utility as a body size index in hummingbirds. Future investigations should focus on variation of skeletal correlates across the full spectrum of body sizes (~2 to 20 g) observed in hummingbirds and possible systematic differences between the typical hummingbirds (Trochilinae) and hermits (Phaethornithinae) in correlation matrices.

Table 2. Correlations (r) between body weight and skeletal characters of *Trochilus scitulus* (Black-billed Streamertail).

Variable	Weight at capture	Weight after holding
Skull width	0.22	0.34
Coracoid	0.52*	0.60*
Humerus length	0.67*	0.71**
Humerus width	0.20	0.19
Femur	0.54*	0.70**
Tibiotarsus	0.30	0.34
Tarsometatarsus	0.49*	0.49*
Sternum length	0.73**	0.75**
Keel length	0.68**	0.64*
Keel depth	0.47*	0.53*
PCA I (10 characters)	0.67*	0.73**
PCA 1 (sternum only)	0.71**	0.72**

*P < 0.05; **P < 0.001.

Discussion

The majority of museum specimens were collected more than 50 years ago in an era before body weight was routinely recorded on specimen labels. Most hummingbird specimens with weight data were obtained with mist nets, but few collectors reported the time interval between capture and weighing on specimen labels. In general practice, mist-netted specimens are held in cloth bags for a few hours before preparation, suggesting that weight loss observed in this study may be typical for museum specimens. However, the time interval between capture and weighing may be a significant source of weight variation observed in museum specimens. An additional problem is that most museum specimens were weighed with 30 g spring scales (and less frequently, 10 g scales) which require interpolation between marked intervals. Rounding error alone is enough to obscure significant inter-specific variation among small species (> 4 g). Consequently, weight data associated with museum specimens may not be of sufficient quality to answer questions such as, "what is the smallest species of hummingbird?"

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