Distributional General Linear Model Specifications

Wrangham, R.W. & Worthington, S. (2024). Apparent stasis of endocranial volume in two chimpanzee subspecies. *American Journal of Biological Anthropology*.

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1 Models for Absolute Effects

1.1 *Absolute Endocranial Volume by Taxon and Sex*

$$\begin{aligned}
\mathrm{ECV}_i &\sim \mathrm{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\mathit{P.t.schweinfurthii}_i) + \beta_2(\mathrm{Male}_i) \\
&\quad + \beta_3(\mathit{P.t.schweinfurthii}_i \times \mathrm{Male}_i) \\
\log \sigma_i &= \gamma_1(\mathit{P.t.schweinfurthii}_i) + \gamma_2(\mathrm{Male}_i) + \gamma_3(\mathit{P.t.schweinfurthii}_i \times \mathrm{Male}_i) \\
\beta_0 &\sim \mathrm{Student}(3,\, 385.6,\, 35) \\
\beta_{1-3} &\sim \mathrm{Student}(3,\, 0,\, 35) \\
\gamma_{1-3} &\sim \mathrm{Cauchy}(0,\, 2)
\end{aligned}$$

1.2 *Absolute Endocranial Volume by Country and Sex*

$$\begin{aligned}
\mathrm{ECV}_i &\sim \mathrm{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\mathrm{Ivory\ Coast}_i) + \beta_2(\mathrm{Liberia}_i) + \beta_3(\mathrm{Uganda}_i) + \beta_4(\mathrm{Male}_i) \\
&\quad + \beta_5(\mathrm{Ivory\ Coast}_i \times \mathrm{Male}_i) + \beta_6(\mathrm{Liberia}_i \times \mathrm{Male}_i) + \beta_7(\mathrm{Uganda}_i \times \mathrm{Male}_i) \\
\log \sigma_i &= \gamma_1(\mathrm{DR\ Congo}_i) + \gamma_2(\mathrm{Ivory\ Coast}_i) + \gamma_3(\mathrm{Liberia}_i) + \gamma_4(\mathrm{Uganda}_i) + \gamma_5(\mathrm{Male}_i) \\
\beta_0 &\sim \mathrm{Student}(3,\, 385.6,\, 35) \\
\beta_{1-7} &\sim \mathrm{Student}(3,\, 0,\, 35) \\
\gamma_{1-5} &\sim \mathrm{Cauchy}(0,\, 2)
\end{aligned}$$

1.3 *Absolute Endocranial Volume by Ugandan Population and Sex*

$$\begin{aligned}
\mathrm{ECV}_i &\sim \mathrm{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\mathrm{Kibale}_i) + \beta_2(\mathrm{Semliki}_i) + \beta_3(\mathrm{Male}_i) \\
&\quad + \beta_4(\mathrm{Kibale}_i \times \mathrm{Male}_i) + \beta_5(\mathrm{Semliki}_i \times \mathrm{Male}_i) \\
\log \sigma_i &= \gamma_1(\mathrm{Budongo}_i) + \gamma_2(\mathrm{Kibale}_i) + \gamma_3(\mathrm{Semliki}_i) + \gamma_4(\mathrm{Male}_i) \\
\beta_0 &\sim \mathrm{Student}(3,\, 385.6,\, 35) \\
\beta_{1-5} &\sim \mathrm{Student}(3,\, 0,\, 35) \\
\gamma_{1-4} &\sim \mathrm{Cauchy}(0,\, 2)
\end{aligned}$$

1.4 *Absolute Endocranial Volume by Kibale Community and Sex*

$$\begin{aligned}
\text{ECV}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\text{Kanyawara}_i) + \beta_2(\text{Sebitoli}_i) + \beta_3(\text{Male}_i) \\
&\quad + \beta_4(\text{Kanyawara}_i \times \text{Male}_i) + \beta_5(\text{Sebitoli}_i \times \text{Male}_i) \\
\log \sigma_i &= \gamma_1(\text{Ngogo}_i) + \gamma_2(\text{Kanyawara}_i) + \gamma_3(\text{Sebitoli}_i) + \gamma_4(\text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 385.6,\, 35) \\
\beta_{1-5} &\sim \text{Student}(3,\, 0,\, 35) \\
\gamma_{1-4} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}$$

1.5 *Femoral Head Diameter by Taxon and Sex*

$$\begin{aligned}
\text{FHD}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\textit{P.t.schweinfurthii}_i) + \beta_2(\text{Male}_i) \\
&\quad + \beta_3(\textit{P.t.schweinfurthii}_i \times \text{Male}_i) \\
\log \sigma_i &= \gamma_1(\textit{P.t.schweinfurthii}_i) + \gamma_2(\text{Male}_i) + \gamma_3(\textit{P.t.schweinfurthii}_i \times \text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 32,\, 2.5) \\
\beta_{1-3} &\sim \text{Student}(3,\, 0,\, 2.5) \\
\gamma_{1-3} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}$$

1.6 *Absolute Bizygomatic Breadth by Taxon and Sex*

$$\begin{aligned}
\text{BZB}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\textit{P.t.schweinfurthii}_i) + \beta_2(\text{Male}_i) \\
&\quad + \beta_3(\textit{P.t.schweinfurthii}_i \times \text{Male}_i) \\
\log \sigma_i &= \gamma_1(\textit{P.t.schweinfurthii}_i) + \gamma_2(\text{Male}_i) + \gamma_3(\textit{P.t.schweinfurthii}_i \times \text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 123.5,\, 8) \\
\beta_{1-3} &\sim \text{Student}(3,\, 0,\, 8) \\
\gamma_{1-3} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}$$

1.7 *Absolute Bizygomatic Breadth by Country and Sex*

$$\begin{aligned}
\text{BZB}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\text{Ivory Coast}_i) + \beta_2(\text{Liberia}_i) + \beta_3(\text{Uganda}_i) + \beta_4(\text{Male}_i) \\
&\quad + \beta_5(\text{Ivory Coast}_i \times \text{Male}_i) + \beta_6(\text{Liberia}_i \times \text{Male}_i) + \beta_7(\text{Uganda}_i \times \text{Male}_i) \\
\log \sigma_i &= \gamma_1(\text{DR Congo}_i) + \gamma_2(\text{Ivory Coast}_i) + \gamma_3(\text{Liberia}_i) + \gamma_4(\text{Uganda}_i) + \gamma_5(\text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 123.5,\, 8) \\
\beta_{1-7} &\sim \text{Student}(3,\, 0,\, 8) \\
\gamma_{1-5} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}$$

1.8 *Absolute Palate Length by Taxon and Sex*

$$
\begin{aligned}
\text{PAL}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\textit{P.t.schweinfurthii}_i) + \beta_2(\text{Male}_i) \\
&\quad + \beta_3(\textit{P.t.schweinfurthii}_i \times \text{Male}_i) \\
\log \sigma_i &= \gamma_1(\textit{P.t.schweinfurthii}_i) + \gamma_2(\text{Male}_i) + \gamma_3(\textit{P.t.schweinfurthii}_i \times \text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 69.9,\, 5) \\
\beta_{1-3} &\sim \text{Student}(3,\, 0,\, 5) \\
\gamma_{1-3} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}
$$

1.9 *Absolute Palate Length by Country and Sex*

$$
\begin{aligned}
\text{PAL}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\text{Ivory Coast}_i) + \beta_2(\text{Liberia}_i) + \beta_3(\text{Uganda}_i) + \beta_4(\text{Male}_i) \\
&\quad + \beta_5(\text{Ivory Coast}_i \times \text{Male}_i) + \beta_6(\text{Liberia}_i \times \text{Male}_i) + \beta_7(\text{Uganda}_i \times \text{Male}_i) \\
\log \sigma_i &= \gamma_1(\text{DR Congo}_i) + \gamma_2(\text{Ivory Coast}_i) + \gamma_3(\text{Liberia}_i) + \gamma_4(\text{Uganda}_i) + \gamma_5(\text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 69.9,\, 5) \\
\beta_{1-7} &\sim \text{Student}(3,\, 0,\, 5) \\
\gamma_{1-5} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}
$$

2 Models for Effects Relative to Body Size (FHD)

2.1 Relative Endocranial Volume by Taxon and Sex

$$
\begin{aligned}
\text{ECV}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\textit{P.t.schweinfurthii}_i) + \beta_2(\text{Male}_i) + \beta_3(\text{FHD}_i) \\
&\quad + \beta_4(\textit{P.t.schweinfurthii}_i \times \text{Male}_i) + \beta_5(\textit{P.t.schweinfurthii}_i \times \text{FHD}_i) \\
&\quad + \beta_6(\text{Male}_i \times \text{FHD}_i) + \beta_7(\textit{P.t.schweinfurthii}_i \times \text{Male}_i \times \text{FHD}_i) \\
\log \sigma_i &= \gamma_1(\textit{P.t.schweinfurthii}_i) + \gamma_2(\text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 385.6,\, 35) \\
\beta_{1-7} &\sim \text{Student}(3,\, 0,\, 35) \\
\gamma_{1-2} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}
$$

2.2 Relative Endocranial Volume by Country and Sex

$$
\begin{aligned}
\text{ECV}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\text{Ivory Coast}_i) + \beta_2(\text{Uganda}_i) + \beta_3(\text{Male}_i) + \beta_4(\text{FHD}_i) \\
&\quad + \beta_5(\text{Ivory Coast}_i \times \text{Male}_i) + \beta_6(\text{Uganda}_i \times \text{Male}_i) + \beta_7(\text{Male}_i \times \text{FHD}_i) \\
&\quad + \beta_8(\text{Ivory Coast}_i \times \text{FHD}_i) + \beta_9(\text{Uganda}_i \times \text{FHD}_i) \\
&\quad + \beta_{10}(\text{Ivory Coast}_i \times \text{Male}_i \times \text{FHD}_i) + \beta_{11}(\text{Uganda}_i \times \text{Male}_i \times \text{FHD}_i) \\
\log \sigma_i &= \gamma_1(\text{DR Congo}_i) + \gamma_2(\text{Ivory Coast}_i) + \gamma_3(\text{Uganda}_i) + \gamma_4(\text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 385.6,\, 35) \\
\beta_{1-11} &\sim \text{Student}(3,\, 0,\, 35) \\
\gamma_{1-4} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}
$$

2.3 Relative Endocranial Volume by Ugandan Population and Sex

$$
\begin{aligned}
\text{ECV}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\text{Kibale}_i) + \beta_2(\text{Semliki}_i) + \beta_3(\text{Male}_i) + \beta_4(\text{FHD}_i) \\
&\quad + \beta_5(\text{Kibale}_i \times \text{Male}_i) + \beta_6(\text{Semliki}_i \times \text{Male}_i) + \beta_7(\text{Male}_i \times \text{FHD}_i) \\
\log \sigma_i &= \gamma_1(\text{Budongo}_i) + \gamma_2(\text{Kibale}_i) + \gamma_3(\text{Semliki}_i) + \gamma_4(\text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 385.6,\, 35) \\
\beta_{1-7} &\sim \text{Student}(3,\, 0,\, 35) \\
\gamma_{1-4} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}
$$

2.4 Relative Endocranial Volume by Kibale Community and Sex

$$
\begin{aligned}
\text{ECV}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\text{Kanyawara}_i) + \beta_2(\text{Sebitoli}_i) + \beta_3(\text{Male}_i) + \beta_4(\text{FHD}_i) \\
&\quad + \beta_5(\text{Kanyawara}_i \times \text{Male}_i) + \beta_6(\text{Sebitoli}_i \times \text{Male}_i) + \beta_7(\text{Male}_i \times \text{FHD}_i) \\
\log \sigma_i &= \gamma_1(\text{Ngogo}_i) + \gamma_2(\text{Kanyawara}_i) + \gamma_3(\text{Sebitoli}_i) + \gamma_4(\text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 385.6,\, 35) \\
\beta_{1-7} &\sim \text{Student}(3,\, 0,\, 35) \\
\gamma_{1-4} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}
$$

2.5 Relative Bizygomatic Breadth by Taxon and Sex

$$
\begin{aligned}
\text{BZB}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\textit{P.t.schweinfurthii}_i) + \beta_2(\text{Male}_i) + \beta_3(\text{FHD}_i) \\
&\quad + \beta_4(\textit{P.t.schweinfurthii}_i \times \text{Male}_i) + \beta_5(\textit{P.t.schweinfurthii}_i \times \text{FHD}_i) \\
&\quad + \beta_6(\text{Male}_i \times \text{FHD}_i) + \beta_7(\textit{P.t.schweinfurthii}_i \times \text{Male}_i \times \text{FHD}_i) \\
\log \sigma_i &= \gamma_1(\textit{P.t.schweinfurthii}_i) + \gamma_2(\text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 123.5,\, 8) \\
\beta_{1-7} &\sim \text{Student}(3,\, 0,\, 8) \\
\gamma_{1-2} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}
$$

2.6 Relative Bizygomatic Breadth by Country and Sex

$$
\begin{aligned}
\text{BZB}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\text{Ivory Coast}_i) + \beta_2(\text{Uganda}_i) + \beta_3(\text{Male}_i) + \beta_4(\text{FHD}_i) \\
&\quad + \beta_5(\text{Ivory Coast}_i \times \text{Male}_i) + \beta_6(\text{Uganda}_i \times \text{Male}_i) + \beta_7(\text{Male}_i \times \text{FHD}_i) \\
&\quad + \beta_8(\text{Ivory Coast}_i \times \text{FHD}_i) + \beta_9(\text{Uganda}_i \times \text{FHD}_i) \\
&\quad + \beta_{10}(\text{Ivory Coast}_i \times \text{Male}_i \times \text{FHD}_i) + \beta_{11}(\text{Uganda}_i \times \text{Male}_i \times \text{FHD}_i) \\
\log \sigma_i &= \gamma_1(\text{DR Congo}_i) + \gamma_2(\text{Ivory Coast}_i) + \gamma_3(\text{Uganda}_i) + \gamma_4(\text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 123.5,\, 8) \\
\beta_{1-11} &\sim \text{Student}(3,\, 0,\, 8) \\
\gamma_{1-4} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}
$$

2.7 *Relative Palate Length by Taxon and Sex*

$$
\begin{aligned}
\text{PAL}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\textit{P.t.schweinfurthii}_i) + \beta_2(\text{Male}_i) + \beta_3(\text{FHD}_i) \\
&\quad + \beta_4(\textit{P.t.schweinfurthii}_i \times \text{Male}_i) + \beta_5(\textit{P.t.schweinfurthii}_i \times \text{FHD}_i) \\
&\quad + \beta_6(\text{Male}_i \times \text{FHD}_i) + \beta_7(\textit{P.t.schweinfurthii}_i \times \text{Male}_i \times \text{FHD}_i) \\
\log \sigma_i &= \gamma_1(\textit{P.t.schweinfurthii}_i) + \gamma_2(\text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 69.9,\, 5) \\
\beta_{1-7} &\sim \text{Student}(3,\, 0,\, 5) \\
\gamma_{1-2} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}
$$

2.8 *Relative Palate Length by Country and Sex*

$$
\begin{aligned}
\text{PAL}_i &\sim \text{Normal}(\mu_i,\, \sigma_i) \\
\mu_i &= \beta_0 + \beta_1(\text{Ivory Coast}_i) + \beta_2(\text{Uganda}_i) + \beta_3(\text{Male}_i) + \beta_4(\text{FHD}_i) \\
&\quad + \beta_5(\text{Ivory Coast}_i \times \text{Male}_i) + \beta_6(\text{Uganda}_i \times \text{Male}_i) + \beta_7(\text{Male}_i \times \text{FHD}_i) \\
&\quad + \beta_8(\text{Ivory Coast}_i \times \text{FHD}_i) + \beta_9(\text{Uganda}_i \times \text{FHD}_i) \\
&\quad + \beta_{10}(\text{Ivory Coast}_i \times \text{Male}_i \times \text{FHD}_i) + \beta_{11}(\text{Uganda}_i \times \text{Male}_i \times \text{FHD}_i) \\
\log \sigma_i &= \gamma_1(\text{DR Congo}_i) + \gamma_2(\text{Ivory Coast}_i) + \gamma_3(\text{Uganda}_i) + \gamma_4(\text{Male}_i) \\
\beta_0 &\sim \text{Student}(3,\, 69.9,\, 5) \\
\beta_{1-11} &\sim \text{Student}(3,\, 0,\, 5) \\
\gamma_{1-4} &\sim \text{Cauchy}(0,\, 2)
\end{aligned}
$$