

# Supplementary Material

## Neural Correlates of Vocal Repertoire in Primates

Jacob C. Dunn\* & Jeroen B. Smaers

\* **Correspondence:** Corresponding Author: jacob.dunn@anglia.ac.uk

### Supplementary Tables

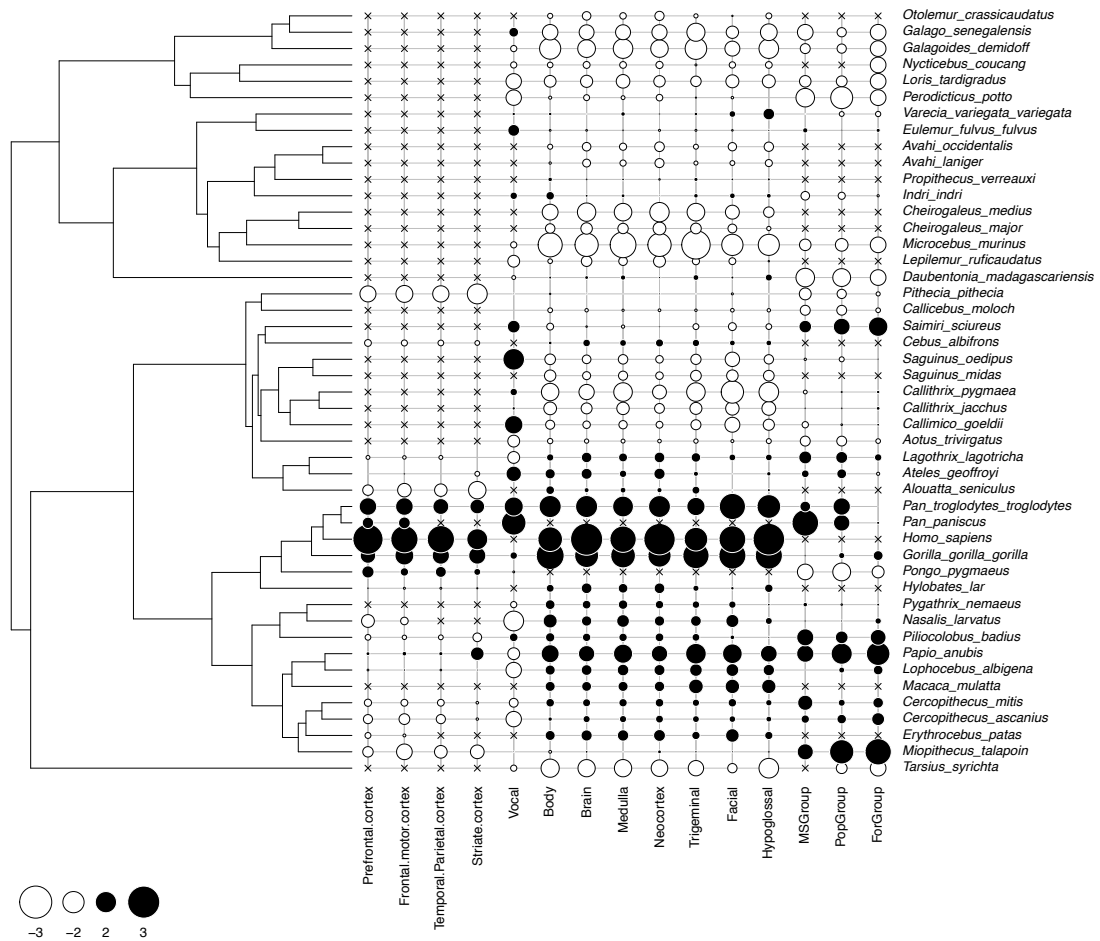
**Table S1.** Raw data on vocal repertoire, group size, body size (g) and brain region volumes (mm<sup>3</sup>) for all species

| Species                             | VR | MS Group | Pop Group | For Group | Body -size | Brain   | Neo-cortex | Pre-frontal | Frontal – motor | Temporal - Parietal | Striate | Medulla | Trigeminal | Facial | Hypogloss |
|-------------------------------------|----|----------|-----------|-----------|------------|---------|------------|-------------|-----------------|---------------------|---------|---------|------------|--------|-----------|
| <i>Alouatta-seneculus</i>           |    |          |           |           | 6400       | 49009   | 31660      | 1014.8      | 1076.7          | 12394.0             | 1918.0  | 1593.3  | 2.3        | 1.7    | 1.6       |
| <i>Aotus-trivirgatus</i>            | 6  | 3.5      | 3.3       | 3.3       | 830        | 16195   | 9950       |             |                 |                     |         | 675.3   | 0.9        | 1.2    | 0.9       |
| <i>Ateles-geoffroyi</i>             | 24 | 19.75    | 22.7      | 3.9       | 8000       | 101034  | 70856      | 2772.5      | 3119.0          | 32933.0             | 3753.0  | 1833.7  | 1.8        | 1.7    | 1.8       |
| <i>Avahi-laniger</i>                |    |          |           |           | 1285       | 10490   | 4813       |             |                 |                     |         | 553.4   | 0.9        | 1.1    | 0.7       |
| <i>Avahi-occidentalis</i>           |    |          |           |           | 860        | 9670    | 4443       |             |                 |                     |         | 508.5   | 0.8        | 0.8    | 0.6       |
| <i>Callicebus-moloch</i>            | 11 | 3.5      | 3.3       | 3.3       | 900        | 17944   | 11163      |             |                 |                     |         | 786.8   | 1.0        | 1.2    | 1.0       |
| <i>Callimico-goeldii</i>            | 28 | 5        | 7.4       | 7.4       | 480        | 11000   | 6476       |             |                 |                     |         | 460.1   | 0.6        | 0.5    | 0.5       |
| <i>Callithrix-jacchus</i>           | 13 | 8.9      | 8.2       | 8.2       | 280        | 7241    | 4371       |             |                 |                     |         | 318.2   | 0.5        | 0.5    | 0.4       |
| <i>Callithrix-pygmaea</i>           | 16 | 6.4      | 7.9       | 7.9       | 140        | 4302    | 2535       |             |                 |                     |         | 185.0   | 0.3        | 0.3    | 0.3       |
| <i>Cebus-albifrons</i>              |    |          |           |           | 3100       | 66939   | 46429      | 1433.9      | 1976.8          | 21024.0             | 3764.0  | 1738.3  | 2.2        | 2.5    | 2.0       |
| <i>Cercopithecus-ascanius</i>       | 5  | 21       | 22        | 22        | 3400       | 63505   | 45166      | 1153.5      | 1351.3          | 16060.0             | 4272.0  | 1802.1  | 2.1        | 2.6    | 2.0       |
| <i>Cercopithecus-mitis</i>          | 7  | 41       | 17.1      | 17.1      | 6300       | 70564   | 49933      | 1379.9      | 1852.4          | 19385.0             | 4232.0  | 1998.9  | 2.1        | 3.1    | 2.1       |
| <i>Cheirogaleus-major</i>           |    |          |           |           | 450        | 6800    | 2938       |             |                 |                     |         | 381.6   | 0.5        | 0.8    | 0.9       |
| <i>Cheirogaleus-medius</i>          |    |          |           |           | 177        | 2961    | 1221       |             |                 |                     |         | 202.4   | 0.3        | 0.5    | 0.6       |
| <i>Daubentonia-madagascariensis</i> | 9  | 1.5      | 1.5       | 1         | 2800       | 42611   | 22127      |             |                 |                     |         | 1517.1  | 1.9        | 2.0    | 2.2       |
| <i>Erythrocebus-patas</i>           |    |          |           |           | 7800       | 103167  | 77141      | 1560.2      | 2552.1          |                     |         | 2615.7  | 2.3        | 4.6    | 2.4       |
| <i>Eulemur-fulvus-fulvus</i>        | 11 | 15.5     | 8.5       | 8.5       | 1400       | 22106   | 12207      |             |                 |                     |         | 909.4   | 1.0        | 1.4    | 1.5       |
| <i>Galago-senegalensis</i>          | 18 | 2        | 3.5       | 1         | 186        | 4512    | 2139       |             |                 |                     |         | 254.3   | 0.3        | 0.6    | 0.4       |
| <i>Galagoides-demidoff</i>          | 8  | 3.5      | 3.5       | 1         | 81         | 3203    | 1568       |             |                 |                     |         | 169.1   | 0.2        | 0.5    | 0.3       |
| <i>Gorilla-gorilla-</i>             | 16 | 9        | 15.8      | 15.8      | 105000     | 470359  | 341444     | 11641.7     | 14854.1         | 125539.0            | 12062.0 | 8393.9  | 9.5        | 13.3   | 10.2      |
| <i>Homo-sapiens</i>                 |    |          |           |           | 65000      | 1251847 | 1006525    | 46322.9     | 29012.6         | 271891.0            | 14787.0 | 9699.8  | 7.7        | 13.0   | 14.4      |
| <i>Hylobates-lar</i>                |    |          |           |           | 5700       | 97505   | 65800      | 2588.2      | 2744.4          | 28424.0             | 4574.0  | 2249.2  | 2.0        | 2.1    | 2.4       |
| <i>Indri-indri</i>                  | 9  | 4        | 4.3       | 4.3       | 6250       | 38300   | 20114      |             |                 |                     |         | 1342.0  | 1.7        | 2.5    | 1.8       |
| <i>Lagothrix-lagoitricha</i>        | 6  | 33       | 28        | 12.1      | 5200       | 95503   | 65873      | 1887.2      | 2433.6          | 24188.0             | 4856.0  | 2109.5  | 2.6        | 2.7    | 2.1       |
| <i>Lepilemur-ruficaudatus</i>       | 6  |          |           |           | 915        | 7600    | 3282       |             |                 |                     |         | 449.3   | 0.7        | 0.9    | 1.2       |
| <i>Lophocebus-albigena</i>          | 5  | 9.5      | 15.5      | 15.5      | 7900       | 97603   | 68733      | 2310.7      | 3925.9          | 29102.0             | 5420.0  | 2670.6  | 3.3        | 4.3    | 3.1       |
| <i>Loris-tardigradus</i>            | 5  | 3        | 3         | 1         | 322        | 6269    | 3524       |             |                 |                     |         | 287.2   | 0.5        | 0.6    | 0.5       |
| <i>Macaca-mulatta</i>               |    |          |           |           | 7800       | 87896   | 63482      |             |                 |                     |         | 2329.1  | 3.8        | 4.9    | 3.9       |
| <i>Microcebus-murinus</i>           | 8  | 3        | 2.5       | 1         | 54         | 1680    | 739.51     |             |                 |                     |         | 99.0    | 0.1        | 0.3    | 0.3       |
| <i>Miopithecus-talapoin</i>         | 12 | 45       | 92.6      | 92.6      | 1200       | 37776   | 26427      | 1018.1      | 906.2           | 12218.0             | 2339.0  | 1034.8  | 1.5        | 1.9    | 1.2       |
| <i>Nasalis-larvatus</i>             | 4  | 9        | 10.8      | 10.8      | 14000      | 92797   | 62685      | 812.7       | 1749.0          |                     |         | 2945.2  | 2.8        | 4.4    | 2.2       |
| <i>Nycticebus-cougang</i>           | 8  |          |           | 1         | 800        | 11755   | 6192       |             |                 |                     |         | 528.1   | 1.0        | 1.0    | 0.8       |
| <i>Otolemur-crassicaudatus</i>      |    |          |           |           | 850        | 9668    | 4723       |             |                 |                     |         | 539.9   | 0.9        | 1.4    | 0.8       |
| <i>Pan-paniscus</i>                 | 38 | 125      | 43.4      | 7.6       |            |         |            | 7955.8      | 8355.5          |                     |         |         |            |        |           |
| <i>Pan-troglodytes</i>              | 29 | 26.5     | 47.6      | 5.6       | 46000      | 382103  | 291592     | 14209.4     | 13406.6         | 112750.0            | 10593.0 | 6027.4  | 5.1        | 12.3   | 7.8       |
| <i>Papio-ambis</i>                  | 6  | 50       | 69        | 69        | 25000      | 190957  | 140142     | 3920.8      | 4685.6          | 45240.0             | 10001.0 | 5171.2  | 6.2        | 7.4    | 4.6       |
| <i>Perodicticus-potto</i>           | 5  | 1.5      | 1         | 1         | 1150       | 13212   | 6683       |             |                 |                     |         | 679.7   | 1.1        | 1.3    | 1.3       |
| <i>Ptilocolobus-badius</i>          | 17 | 49.5     | 30.2      | 30.2      | 7000       | 73818   | 50906      | 1591.3      | 2260.2          | 22629.0             | 3053.0  | 2007.1  | 2.2        | 2.3    | 1.5       |
| <i>Pithecia-pithecia</i>            | 12 | 2.9      | 3.5       | 3.5       | 1500       | 32867   | 21028      | 600.4       | 819.1           | 9242.0              | 1679.0  | 1008.9  | 1.3        | 1.3    | 1.4       |
| <i>Pongo-pygmaeus</i>               | 10 | 2        | 1.5       | 1.5       |            |         |            | 8595.7      | 6353.1          | 76924.0             | 7008.0  |         |            |        |           |
| <i>Propithecus-verreauxi</i>        |    |          |           |           | 3480       | 25194   | 13170      |             |                 |                     |         | 1222.6  | 1.7        | 2.0    | 1.6       |
| <i>Pygathrix-nemaeus</i>            | 8  | 14.5     | 7.5       | 7.5       | 7500       | 77000   | 48763      |             |                 |                     |         | 2206.1  | 2.2        | 2.8    | 1.6       |
| <i>Saguinus-midas</i>               |    |          |           |           | 340        | 10300   | 5883       |             |                 |                     |         | 428.5   | 0.5        | 0.6    | 0.6       |
| <i>Saguinus-oedipus</i>             | 33 | 7.4      | 5.3       | 5.3       | 380        | 9537    | 5894       |             |                 |                     |         | 413.3   | 0.5        | 0.5    | 0.6       |
| <i>Saimiri-sciureus</i>             | 21 | 32       | 45        | 45        | 660        | 22572   | 15541      |             |                 |                     |         | 721.5   | 0.8        | 0.8    | 0.8       |
| <i>Tarsius-syrichta</i>             | 8  |          | 3         | 1         | 125        | 3393    | 1768       |             |                 |                     |         | 206.9   | 0.4        | 0.8    | 0.3       |
| <i>Varecia-variegata-</i>           | 13 | 10.5     | 5.4       | 3.1       | 3000       | 29713   | 15293      |             |                 |                     |         | 1420.0  | 1.6        | 2.7    | 3.1       |

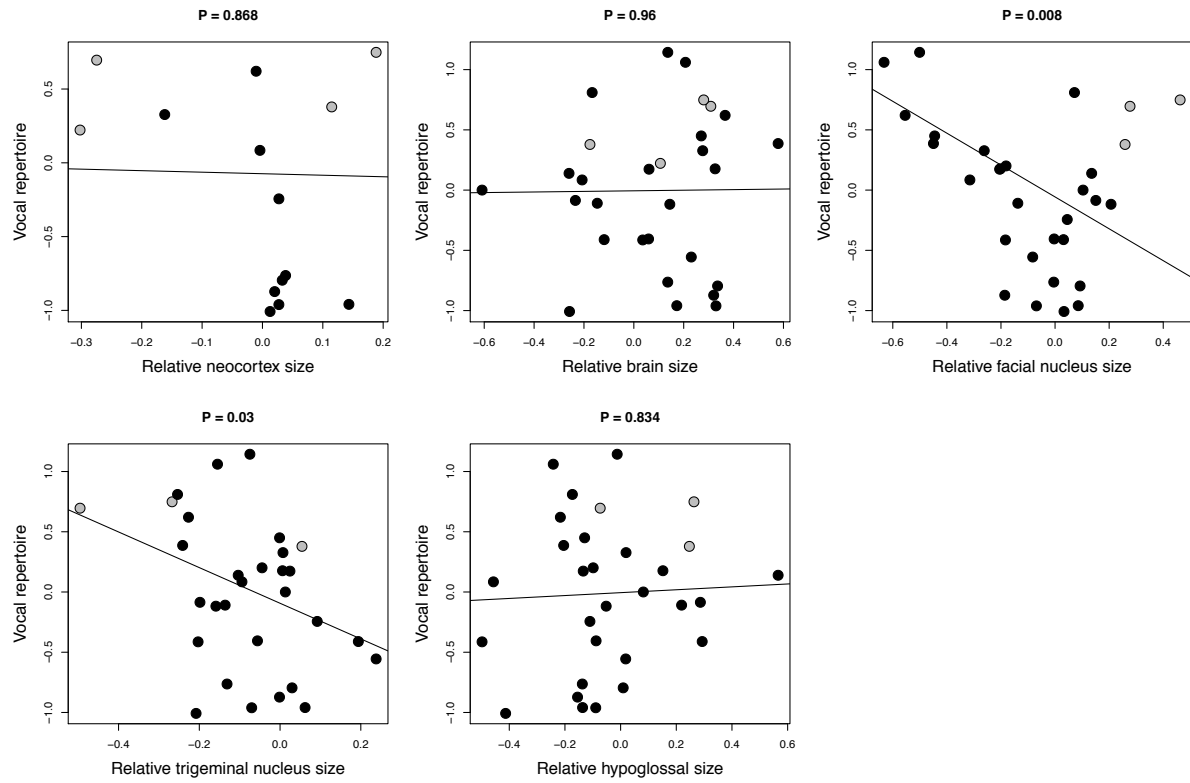
**Table S2.** Equivalent results from main text on the relationship between vocal repertoire and brain structure/area volume, using alternative data on group size

| Group Variable | Brain structure/area | slope | slope_st.err | slope_min | slope_max | intercept | intercept_st.err | intercept_min | intercept_max | Rsquare | Pvalue | Lambda | df |
|----------------|----------------------|-------|--------------|-----------|-----------|-----------|------------------|---------------|---------------|---------|--------|--------|----|
| PopGroup       | Brain                | 0.20  | 0.50         | -0.82     | 1.22      | -0.01     | 0.26             | -0.54         | 0.52          | 0.01    | 0.69   | 0.57   | 28 |
|                | Neocortex            | -0.58 | 0.66         | -2.02     | 0.85      | 0.00      | 0.59             | -1.28         | 1.28          | 0.06    | 0.39   | 1.00   | 28 |
|                | Prefrontal           | 0.94  | 0.23         | 0.42      | 1.46      | -0.05     | 0.12             | -0.31         | 0.20          | 0.62    | 0.00   | 0.00   | 10 |
|                | Frontal motor        | 1.38  | 0.27         | 0.78      | 1.99      | -0.02     | 0.10             | -0.25         | 0.20          | 0.72    | 0.00   | 0.00   | 10 |
|                | Non-frontal          | 1.29  | 0.29         | 0.65      | 1.93      | -0.03     | 0.11             | -0.27         | 0.21          | 0.67    | 0.00   | 0.00   | 10 |
| ForGroup       | Brain                | 0.04  | 0.51         | -1.02     | 1.10      | 0.00      | 0.21             | -0.45         | 0.44          | 0.00    | 0.94   | 0.29   | 28 |
|                | Neocortex            | 2.27  | 3.48         | -5.60     | 10.14     | -0.37     | 0.29             | -1.02         | 0.27          | 0.05    | 0.53   | 0.00   | 28 |
|                | Prefrontal           | 0.66  | 0.28         | 0.02      | 1.29      | 0.03      | 0.14             | -0.28         | 0.34          | 0.35    | 0.04   | 0.00   | 10 |
|                | Frontal motor        | 0.96  | 0.37         | 0.13      | 1.79      | 0.05      | 0.14             | -0.25         | 0.35          | 0.40    | 0.03   | 0.00   | 10 |
|                | Non-frontal          | 0.89  | 0.37         | 0.07      | 1.71      | 0.05      | 0.14             | -0.26         | 0.35          | 0.37    | 0.04   | 0.00   | 10 |
| MSGGroup       | Brain                | 0.02  | 0.48         | -0.97     | 1.02      | -0.01     | 0.31             | -0.63         | 0.62          | 0.00    | 0.96   | 0.71   | 27 |
|                | Neocortex            | -0.10 | 0.60         | -1.42     | 1.21      | -0.07     | 0.54             | -1.25         | 1.10          | 0.00    | 0.87   | 1.00   | 27 |
|                | Prefrontal           | 0.86  | 0.26         | 0.29      | 1.43      | 0.04      | 0.13             | -0.24         | 0.32          | 0.53    | 0.01   | 0.00   | 10 |
|                | Frontal motor        | 1.25  | 0.32         | 0.53      | 1.96      | 0.07      | 0.12             | -0.19         | 0.33          | 0.60    | 0.00   | 0.00   | 10 |
|                | Non-frontal          | 1.16  | 0.33         | 0.44      | 1.89      | 0.06      | 0.12             | -0.22         | 0.33          | 0.56    | 0.01   | 0.00   | 10 |

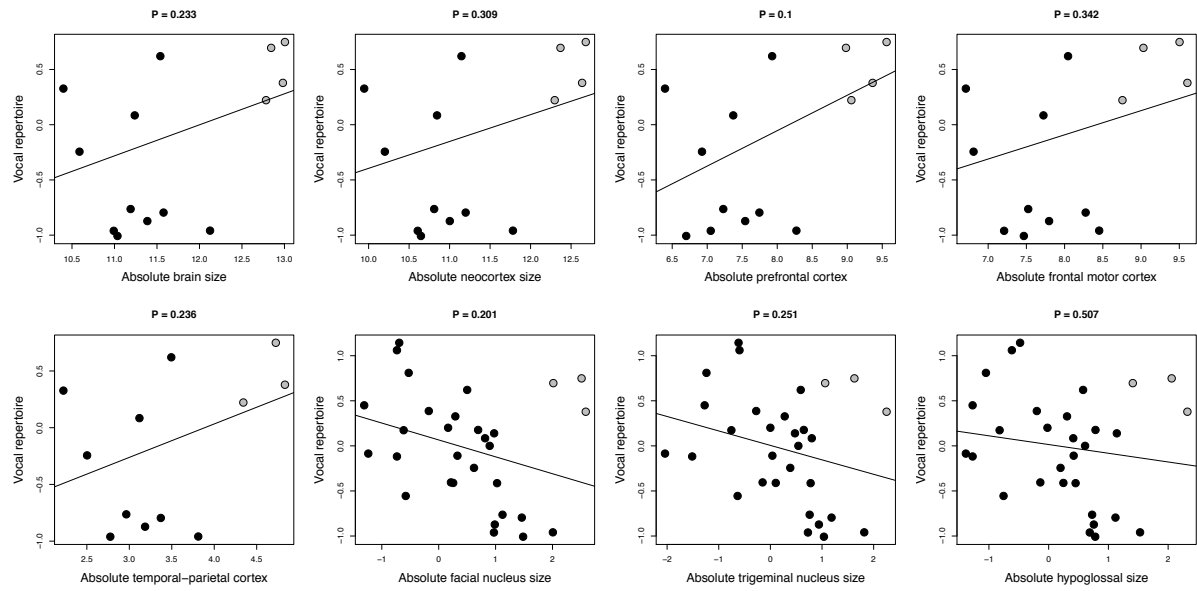
## Supplementary Figures



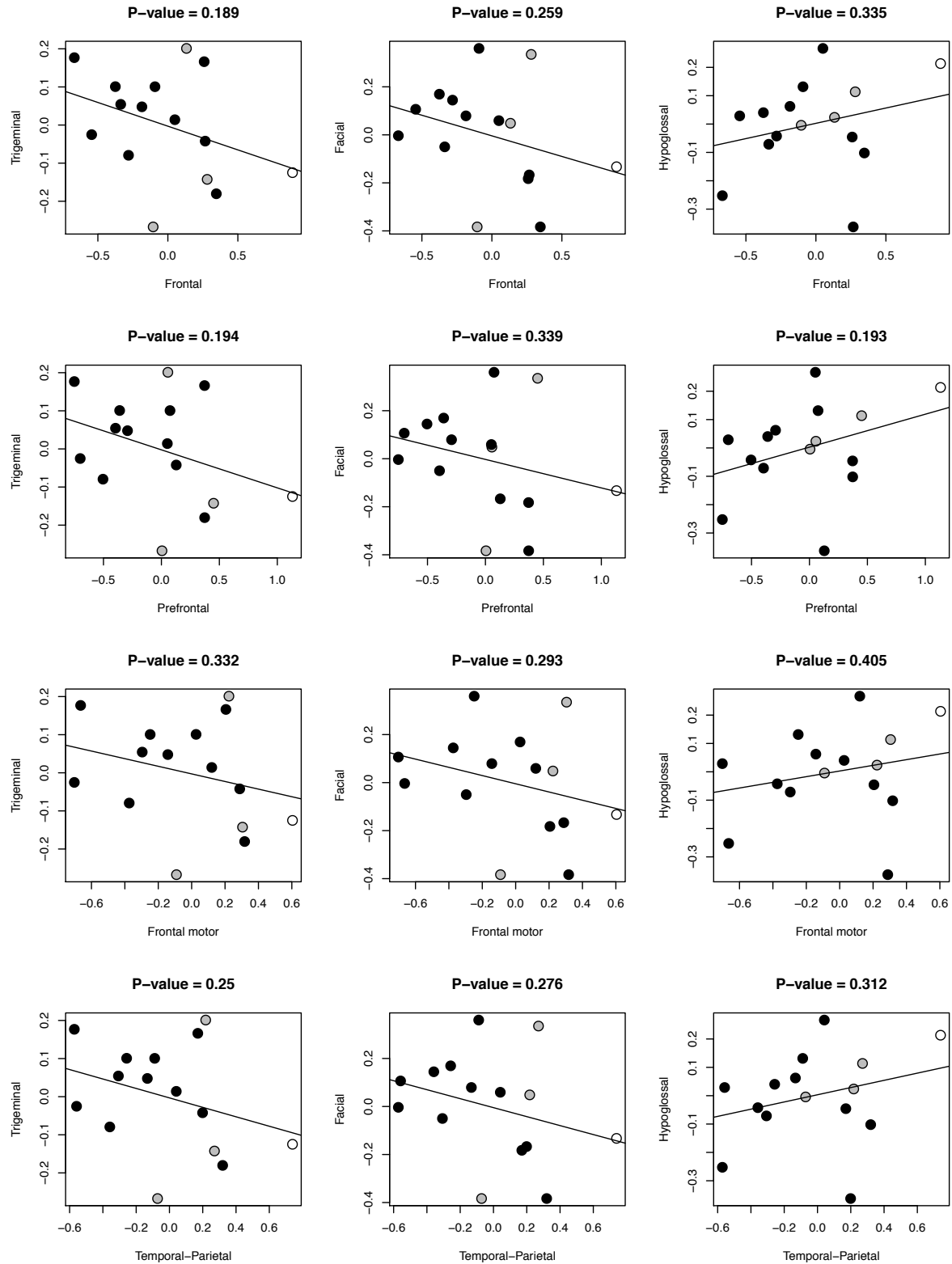
**Figure S1.** Phylogenetic tree of primate species studied and the relative magnitude of the traits studied. The size of the circle for each trait represents standardised scores of the raw data, black circles represent positive values and white circles represent negative values.



**Figure S2.** PGLS regressions of the residual volume of brain regions versus residual vocal repertoire. We represent 95% confidence intervals as dashed lines. Monkeys are represented in black, non-human apes in grey.



**Figure S3.** PGLS regression of absolute brain region volumes versus residual vocal repertoire. We represent 95% confidence intervals as dashed lines. Monkeys are represented in black, non-human apes in grey.



**Figure S4.** PGLS regression of the relative size of cortical association areas to the relative size of the brain stem nuclei. We represent 95% confidence intervals as dashed lines. Monkeys are represented in black, non-human apes in grey, humans in white.