Inferences about Prefrontal Cortex Size in Humans from Motor and Premotor Area Scaling Relationships

INDIANA UNIVERSITY
BLOOMINGTON

P. Thomas Schoenemann[1,2,3]

[1]Department of Anthropology and [2]Cognitive Science Program, Indiana University, [3]Stone Age Institute Program in Human Evolution, Bloomington, Indiana,

Introduction

Disproportionate increased size of particular areas of the human brain, as assessed relative to trends found among primates, suggests that behaviors mediated in those areas have been particularly important during human evolution. One area that has been the focus of several studies is the prefrontal cortex. Early data by Brodmann suggested that it was approximately twice as large as would be predicted for a primate neocortex as large as ours. These data have been called into question recently partly because they do not fit expectations reported from more recent studies. The entire frontal lobe, which includes primary motor (Brodmann area 4) and premotor (Brodmann area 6) areas in addition to the prefrontal cortex, is apparently as large as would be predicted for a brain as large as ours. However, if the prefrontal lobe is in fact disproportionately large, then areas 4 and 6 would therefore necessarily have to be disproportionately small. Data from the literature on the sizes of areas 4 and 6 in a small sample of primates (Glezer 1958) was used to assess this question.

Key question:

Is the human prefrontal cortex disproportionately large, based on primate brain scaling?

Background:

Frontal cortex is not the same as prefrontal cortex:
frontal cortex = prefrontal cortex + premotor cortex + primary motor cortex

The human *frontal* cortex is large, but *not disproportionately* so, based on primate brain scaling (e.g., Semendeferi et al., 1997; Semendeferi et al., 2002).

The human *prefrontal* cortex, conversely, *is* disproportionately large (e.g., Brodmann, 1912; Blinkov & Glezer, 1968; Deacon 1997; Schoenemann 2005)

Recently, these *prefrontal* studies have recently been called into question (Barton & Venditti, 2013)

Another avenue: How do *non-prefrontal* areas scale?? Two possibilities:

1. If both the entire frontal as well as the prefrontal are proportionate to brain size (per Barton & Venditti, 2013), then non-prefrontal areas must also be proportionate

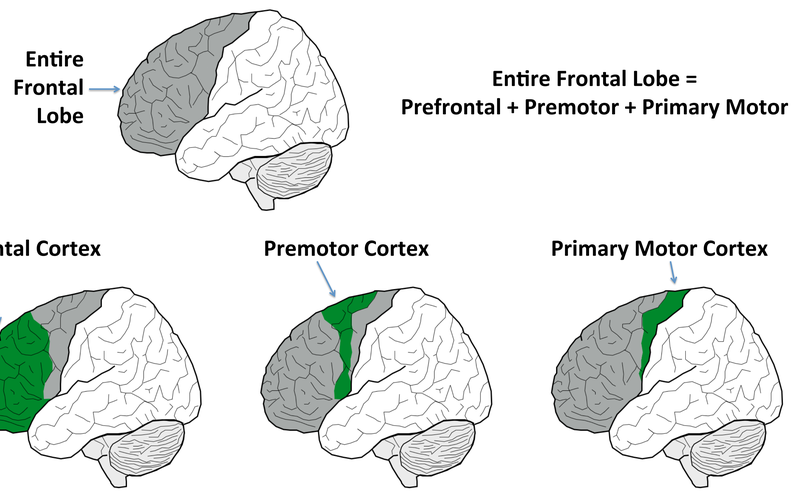
2. If the entire frontal is proportionate to brain size, but the prefrontal sub-region is disproportionately large, the remaining non-prefrontal sub-region must be *disproportionately small*

This logic has been pointed out by, e.g., Preuss (2000), Rilling (2006), Schoenemann (2006).

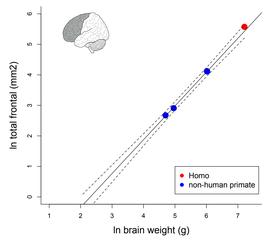
Some comparative data on non-prefrontal regions exist to test this (Glezer, 1958) has long been available, but was not reviewed by Barton & Venditti (2013).

This data was analyzed previously by Deacon (1997), prior to the advent of statistical methods that control for phylogeny. Assessment of this dataset taking phylogeny into account is presented here.

Regions of the Frontal Lobe



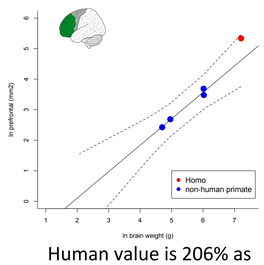
Size of Total Human Frontal Lobe Relative to Non-human Primate Predictions



Human value is 104% as large as predicted

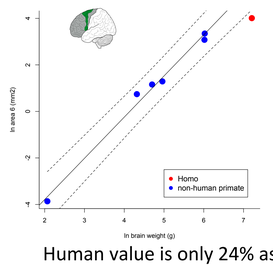
Size of Human Frontal Lobe Sub-Regions Relative to Non-human Primate Predictions

Prefrontal Cortex



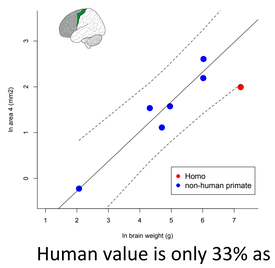
Human value is 206% as large as predicted

Premotor Cortex



Human value is only 24% as large as predicted

Primary Motor Cortex



Human value is only 33% as large as predicted

Materials and Methods

Data:

Frontal lobe sub-region data from: Glezer, I. I. (1958). Area relationships in the precentral region in a comparative anatomical series of primates. *Arkhiv Anatomii, Gistologii I Embriologii*, 2, 26–29.

Species included: *Homo sapiens, Pan troglodytes, Pongo pygmaeus, Hylobates agilis, Papio hamadryas, Cercopithecus mitis, Callithrix jacchus*

Total brain volume compiled from literature sources (Hurst and Schoenemann, in prep.)

Analyses:

1) Simple regression analyses
   A. Natural log transformed variables
   B. Prediction of sub-region size for human-sized brain based on linear regression calculated using non-human primate data excluding human
   C. Calculated ratio of human [actual] ÷ [predicted]

2) Phylogenetic Generalized Least Squares (PGLS)
   A. Using CAPER package (version 0.5.2; Orme et al. 2013) in R (R core team, 2014)
   B. Natural log transformed variables
   C. 10KTrees (Arnold et al. 2010) consensus tree for primates
   D. Lambda value calculated: maximum likelihood estimate of phylogenetic effect (assuming a Brownian motion model of evolutionary change)

Regression Results:

Total Frontal Area

ln(total frontal mm^2) = 1.108 x ln(brain mass g) - 2.556
Multiple R-squared: 0.999, p-value: 0.0004263
PGLS maximum likelihood lambda estimate: 0

Premotor Area

ln(premotor mm^2) = 1.770 x ln(brain mass g) - 7.326
Multiple R-squared: 0.99, p-value: 0.00003703
PGLS maximum likelihood lambda estimate: 0

Primary Motor Area

ln(primary motor mm^2) = 0.650 x ln(brain mass g) - 1.578
Multiple R-squared: 0.93, p-value: 0.00175
PGLS maximum likelihood lambda estimate: 0

Prefrontal Area

ln(prefrontal mm^2) = 0.866 x ln(brain mass g) - 1.628
Multiple R-squared: 0.98, p-value: 0.01046
PGLS maximum likelihood lambda estimate: 0

Conclusions from the data of Glezer (1958):

Human frontal lobe is as large as predicted (consistent with previous studies)

BUT:

Human non-prefrontal areas of the frontal lobe are significantly *smaller* than predicted

Human prefrontal is significantly *larger* than predicted

References

Arnold, C., Matthews, L. J., & Nunn, C. L. (2010). The 10kTrees website: a new online resource for primate phylogeny. *Evolutionary Anthropology: Issues, News, and Reviews*, *19*(3), 114–118.
Barton, R. A., & Venditti, C. (2013). Human frontal lobes are not relatively large. *Proceedings of the National Academy of Sciences*, *110*(22), 9001–9006. doi:10.1073/pnas.1215723110
Glezer, I. I. (1958). Area relationships in the precentral region in a comparative anatomical series of primates. *Arkhiv Anatomii, Gistologii I Embriologii*, *2*, 26–29.
Brodmann, K. (1912). Neue Ergebnisse über die vergleichende histologische localisation der grosshirnrinde mit besonderer berücksichtigung des stirnhirns. *Anatomischer Anzeiger, supplement 41*, 157–216.
Deacon, T. W. (1997). *The symbolic species : the co-evolution of language and the brain*. New York: W.W. Norton.
Orme, D., Freckleton, R., Thomas, G., Petzoldt, T., Fritz, S., Isaac, N., & Pearse, W. (2013). *caper: Comparative Analyses of Phylogenetics and Evolution in R*. Retrieved from http://CRAN.R-project.org/package=caper
R Core Team. (2013). R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing. Retrieved from http://www.R-project.org
Preuss, T. M. (2000). What's human about the human brain? In M. S. Gazzaniga (Ed.), *The New Cognitive Neurosciences, 2nd Edition* (pp. 1219–1234). Cambridge, MA: Bradford Books/MIT Press.
Rilling, J. K. (2006). Human and nonhuman primate brains: are they allometrically scaled versions of the same design? *Evolutionary Anthropology*, *15*, 65–77.
Semendeferi, K., Damasio, H., Frank, R., & Van Hoesen, G. W. (1997). The evolution of the frontal lobes: a volumetric analysis based on three-dimensional reconstructions of magnetic resonance scans of human and ape brains. *J Hum Evol*, *32*(4), 375–88.
Semendeferi, K., Lu, A., Schenker, N., & Damasio, H. (2002). Humans and great apes share a large frontal cortex. *Nat Neurosci*, *5*(3), 272–6.
Schoenemann, P. T., Sheehan, M. J., & Glotzer, L. D. (2005). Prefrontal white matter volume is disproportionately larger in humans than in other primates. *Nature Neuroscience*, *8*(2), 242–52. doi: 10.1038/nn1394