Supporting Information

Garwicz et al. 10.1073/pnas.0905777106

SI Text

Reliability of Data on Adult Brain Mass. Data on adult brain mass for primates, rodents, carnivores, the elephant, and common domestic species were found documented in more than one study. For these species, the values in Table S2 were selected from a total of 58 values from 10 studies and represented, for a given species, the largest sample size or, if the underlying material did not differ significantly in that respect, the median value. The deviation of the remaining 43 values from the values in Table S2 averaged $<10\%$, with a symmetrical distribution above and below the values used. Hence, although the main reference (1) dates 30 years back, data are representative. Because data on the horse brain showed a substantial variation and an asymmetrical distribution, the mean value was calculated for this species and used instead of the median value.

Reliability of Data on Walking Onset. Walking onset refers here to the earliest spontaneously occurring quadrupedal walking (which is palmigrade for nonhuman primates) except for the bipedal gait of man. For most species, the data on walking onset were obtained from original papers explicitly addressing issues of locomotor development. For rodents and carnivores, the timing of walking onset was typically indicated by a dramatic increase in length of path covered in the open field resulting from the change in locomotor efficiency at the transition between crawling and walking, given at a temporal resolution of days. In most cases, this timing was supported by other data based on detailed quantitative analysis of step cycle parameters in the course of development. For nonhuman primates, the timing was often given in descriptive terms at a somewhat lower level of temporal resolution, typically in weeks. Walking onset for all ungulates was taken to occur on postnatal day 1.

1. Sacher GA, Staffeldt EF (1974) Relation of gestation time to brain weight for placental mammals: Implications for the theory of vertebrate growth. *Am Nat* 108:593–615.

2. Felsenstein J (1985) Phylogenies and the comparative method. *Am Nat* 125:1–15.

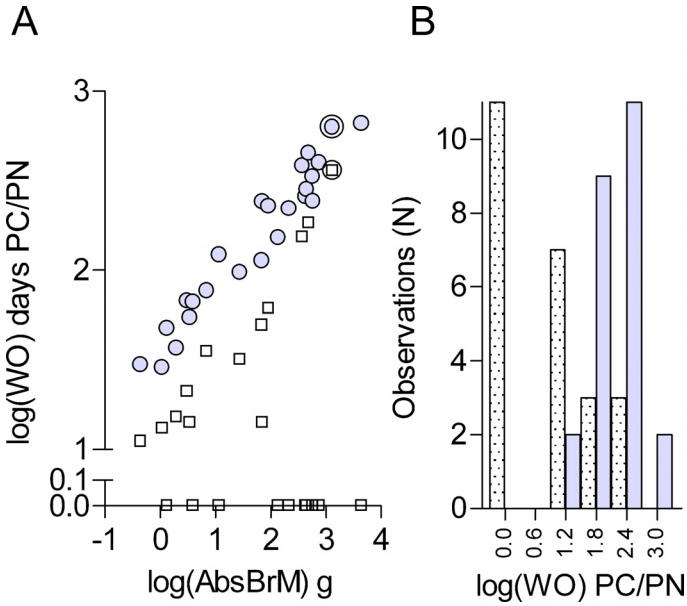

Fig. S1. The significance of using conception rather than birth as point of origin of the developmental timescale when measuring time to walking onset. The limitation of using postnatal dates is most evident for species that start walking soon after birth. For these species, time to walking onset appears constant and cannot vary as a function of any parameter. (*A*) Time to walking onset, log(WO), measured in days postconception (PC, shaded circles) and days postnatal (PN, open squares), as a function of absolute adult brain mass, log(AbsBrM). Sample is shown as in Table S2. Double circle: humans. (*B*) Frequency distribution of time to walking onset for species in *A*, either as days postconception (PC, shaded bars) or days postnatal (PN, stippled bars), both as log values. The Kolmogorov–Smirnov normality test ($\alpha = 0.05$) showed that the PC distribution is compatible with a normal Gaussian distribution ($P > 0.10$), but the PN distribution is not ($P < 0.0001$), supporting that the unit days PC is more biologically relevant than days PN as a measure of time to walking onset.

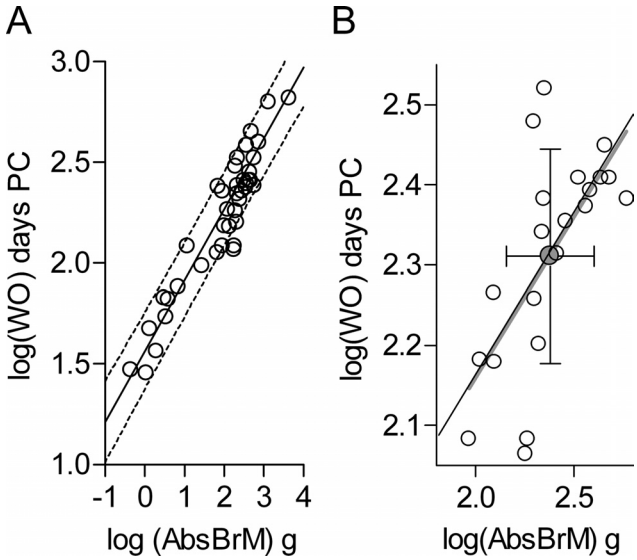

Fig. S2. How general is the validity of the model in the main text? (*A*) Increasing sample size from $n = 24$ to $n = 40$ by including 16 additional species of the order Artiodactyla for which data were available (1) would disturb the balance of the sample with regard to phylogenetic relatedness between species (see ref. 2) but result in virtually no change in slope or *Y*-intercept and only in a modest change in variance of walking onset accounted for by adult brain mass (from 94 to 89%). The *F* value remained high ($F_{(2,23)} = 347$ and $F_{(2,23)} = 302$, respectively). Virtually all added Artiodactyla fell within the 90% prediction (dashed lines) generated by the $n = 24$ sample. Solid line: regression line for $n = 24$. (*B*) To show variation in walking onset varies as a function of absolute adult brain mass *within* vs. *across* taxonomic subcategories, 21 species of the order Artiodactyla (1) were plotted (open circles). Five of these species were included in the model in the main text. Conventions are as in Fig. S1. Note position of mean and SD for all 21 species, represented by a shaded circle with error bars, in relation to the regression line for species that cannot assume a plantigrade standing position (solid line) replotted from Fig. 4 *Left*. The slope and *Y*-intercept of the regression line for Artiodactyla (0.402 and 1.355; shaded line) were highly similar to the slope and *Y*-intercept across taxonomic subcategories (dashed regression line; 0.405 and 1.355).

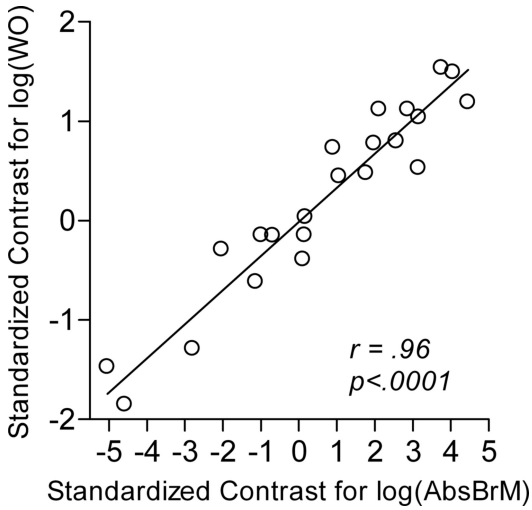

Fig. S3. Evaluating the influence of phylogenetic relatedness on the statistical significance of the findings illustrated in Fig. 4 *Right*. Number of contrasts: 22 (open circles). Solid line: Model II linear regression (reduced major axis). The Pearson correlation coefficient was 0.959 (adj $R^2 = 0.919$, $F_{(1,20)} = 239.4$, $P < 0.0001$), showing that the effects of phylogenetic relatedness were very minor.

Table S1. Taxonomy of species included in the sample

Lay term	Order/suborder	Family	Genus/species
Elephant shrew	Macroscelidea	Macroscelididae	*Elephantulus myurus*
Aardvark	Tubulidentata	Orycteropodidae	*Orycteropus afer*
Elephant	Proboscidea	Elephantidae	*Loxodonta africana*
Armadillo	Cingulata	Dasypodidae	*Dasypus novemcinctus*
Chimpanzee	Primates	Hominidae	*Pan troglodytes*
Human	Primates	Hominidae	*Homo sapiens*
Gorilla	Primates	Hominidae	*Gorilla gorilla*
Macaque	Primates	Cercopithecidae	*Macaca mulatta*
Tree shrew	Scandentia	Tupaiidae	*Tupaia belangeri*
Rat	Rodentia/Myomorpha	Muridae	*Rattus norvegicus*
Mouse	Rodentia/Myomorpha	Muridae	*Mus musculus*
Hamster	Rodentia/Myomorpha	Cricetidae	*Mesocricetus auratus*
Guinea pig	Rodentia/Hystricomorpha	Caviidae	*Cavia porcellus*
Ferret	Carnivora/Caniformia	Mustelidae	*Mustela putorius furo*
Dog	Carnivora/Caniformia	Canidae	*Canis lupus familiaris*
Cat	Carnivora/Feliformia	Felidae	*Felis catus*
Horse	Perissodactyla	Equidae	*Equus caballus*
Sheep	Artiodactyla/Ruminantia	Bovidae	*Ovis aries*
Cow	Artiodactyla/Ruminantia	Bovidae	*Bos taurus*
Chital	Artiodactyla/Ruminantia	Cervidae	*Axis axis*
Elk	Artiodactyla/Ruminantia	Cervidae	*Cervus canadensis*
Hippopotamus	Artiodactyla/Suiformes	Hippopotamidae	*Hippopotamus amphibius*
Camel	Artiodactyla/Tylopoda	Camelidae	*Camelus dromedarius*
Hedgehog	Erinaceomorpha	Erinaceidae	*Erinaceus europaeus*

Species are ordered as in Fig. 1, main text. Lay terms in the left column are used in text, Figs. 1 and 4, and Table S2.

Table S2. Database for multiple-regression model

Species (lay term)	AbsBrM, g	NeoBrM (1), g	BoM, g	Gest., days	WO, days		Pre/Alt	HSP
					PN	PC		
Elephant shrew	1.37 (1)	0.58	64 (1)	46 (1)	1 (2)	47	Pre	Plant.
Aardvark	72 (3)	—	52,000 (3)	225 (3)	14 (3)	239	Alt	Plant.
Elephant	4,480 (1)	1,650	2,750,000 (1)	655 (1)	1	656	Pre	Nonplant.
Armadillo	12 (1)	3.5	3,700 (1)	120 (1)	1 (2)	121	Pre	Plant.
Chimpanzee	382 (4)	128	45,000 (1)	230 (1)	153 (5)	383	Pre	Plant.
Human	1,350 (6)	335	65,000 (1)	270 (1)	357 (7)	627	Pre	Plant.
Gorilla	500 (6)	227	140,000 (1)	265 (1)	183 (5)	448	Pre	Plant.
Macaque	93.8 (8)	55	7,340 (1)	165 (9)	61 (10)	226	Pre	Plant.
Tree shrew	3.15 (1)	0.53	150 (1)	46 (1)	21 (11)	67	Alt	Plant.
Rat	2 (6)	0.28	339 (1)	21.5 (9)	15 (12)	36.5	Alt	Plant.
Mouse	0.45 (1)	0.09	24 (1)	18.5 (9)	11 (13)	29.5	Alt	Plant.
Hamster	1.12 (1)	0.06	125 (1)	15.5 (9)	13 (14)	28.5	Alt	Plant.
Guinea pig	4 (15)	2.52	971 (1)	65 (16)	1 (17)	66	Pre	Plant.
Ferret	7.1 (18)	—	1,800 (2)	41 (9)	35 (19)	76	Alt	Plant.
Cat	28.4 (1)	5.6	2,500 (1)	65 (9)	32 (20)	97	Alt	Nonplant.
Dog	70.2 (1)	6.8	8,480 (1)	63 (1)	49 (21)	112	Alt	Nonplant.
Horse	585 (1, 6)	368	484,000 (1)	330 (1)	1	331	Pre	Nonplant.
Sheep	140 (6)	52	48,800 (1)	150 (1)	1	151	Pre	Nonplant.
Cow	456 (1)	199	520,000 (1)	280 (1)	1	281	Pre	Nonplant.
Chital	219 (1)	78.6	88,500 (1)	218 (1)	1	219	Pre	Nonplant.
Elk	435 (1)	203	200,000 (1)	255 (1)	1	256	Pre	Nonplant.
Hippopotamus	590 (1)	195	1,400,000 (1)	240 (1)	1	241	Pre	Nonplant.
Camel	762 (6)	—	690,000 (2)	395 (22)	1	396	Pre	Nonplant.
Hedgehog	3.5 (1)	0.313	928 (1)	40 (2)	14 (23)	54	Alt	Plant.

Species are ordered according to Fig. 1, main text. AbsBrM, absolute brain mass; NeoBrM, neonatal brain mass; brain advancement at birth = NeoBrM/AbsBrM; BoM, body mass; relative brain mass = adult brain mass/body mass; Gest., gestation time; WO, time to walking onset; PN, postnatal; PC, postconception; walking onset PC = gestation time + walking onset PN; Pre, precocial; Alt, altricial; HSP, hindlimb standing position (lower extremity in humans), differentiates between species that can assume a plantigrade hindlimb standing position (Plant.) and species that cannot (Nonplant.). Of the species listed as "plantigrade," only chimpanzees, gorillas, and humans actually walk with plantigrade posture. The other plantigrade species walk and run with digitigrade posture in which the heel does not contact, or apply force to, the substrate. Elephants are listed as nonplantigrade because their heel is supported above the ground by a large connective tissue pad. During walking force transmission through this pad makes elephants mechanically plantigrade.

1. Sacher GA, Staffeldt EF (1974) Relation of gestation time to brain weight for placental mammals: Implications for the theory of vertebrate growth. *Am Nat* 108:593–615.
2. Hutchins M, et al., eds (2003) *Grzimek's Animal Life Encyclopedia. Mammals I–V* (Gale, Detroit), 2nd Ed, Vols 13–16; cf. University of Michigan Museum of Zoology, Animal Diversity Web, available at http://animaldiversity.ummz.umich.edu/site/index.html.
3. Knöthig J (2005) Biology of the Aardvark (*Orycteropus afer*). PhD thesis (Ruprecht-Karls-University, Heidelberg).
4. DeSilva J, Lesnik J (2006) Chimpanzee neonatal brain size: Implications for brain growth in *Homo erectus*. *J Hum Evol* 51:207–212.
5. Doran DM (1997) Ontogeny of locomotion in mountain gorillas and chimpanzees. *J Hum Evol* 32:323–344.
6. Roth G, Dicke U (2005) Evolution of the brain and intelligence. *Trends Cogn Sci* 9:250–257.
7. Bayley N (1993) *Bayley Scales of Infant Development* (Psychological Corporation, New York).
8. Marino L (1998) A comparison of encephalization between odontocete cetaceans and anthropoid primates. *Brain Behav Evol* 51:230–238.
9. Clancy B, Darlington RB, Finlay BL (2001) Translating developmental time across mammalian species. *Neuroscience* 105:7–17.
10. Dunbar DC, Badam GI (1998) Development of posture and locomotion in free-ranging primates. *Neurosci Biobehav Rev* 22:541–546.
11. Personal communication from Julie Heiner (David Fitzpatrick's laboratory, Duke University Medical Center, Durham, NC) and M.C.; cf. Martin RD (1968) *Z Tierpsychol* 25:505–532.
12. Altman J, Sudarshan K (1975) Postnatal development of locomotion in the laboratory rat. *Anim Behav* 23:896–920.
13. Fox WM (1965) Reflex ontogeny and behavioural development of the mouse. *Anim Behav* 13:234–241.
14. Da Silva VA, Smart JL, Freire EM, Paumgartten FJR (1989) Neurobehavioural development of the golden hamster. *Neurotoxicol Teratol* 11:105–111.
15. Himwich WA (1962) Biochemical and neurophysiological development of the brain in the neonatal period. *Int Rev Neurobiol* 4:117–158.
16. Clancy B, Finlay BL, Darlington RB, Anand KJ (2007) Extrapolating brain development from experimental species to humans. *Neurotoxicology* 28:931–937.
17. Oakley DA, Plotkin HC (1975) Ontogeny of spontaneous locomotor activity in rabbit, rat and guinea pig. *J Comp Physiol Psychol* 89:267–273.
18. Weiler E (1992) Seasonal changes in adult mammalian brain weight. *Naturwissenschaften* 79:274–276.
19. Christensson M, Garwicz M (2005) Time course of postnatal motor development in ferrets: Ontogenetic and comparative perspectives. *Behav Brain Res* 158:231–242.
20. Frederickson CJ, Frederickson MH (1979) Developmental changes in open-field behavior in the kitten. *Dev Psychobiol* 12:623–628.
21. Czarkowska J (1983) Changes of some postural reflexes during the first postnatal weeks in the dog. *Acta Neurobiol Exp* 43:27–35.
22. Skidmore JA (2003) The main challenges facing camel reproduction research in the 21st century. *Reprod Suppl* 61:37–47.
23. Available at http://hedgehogvalley.com/dev.html.