Photomicrographs of vertebrate embryos taken by Lennart Nillson

Energetic Equivalence in Embryonic Development

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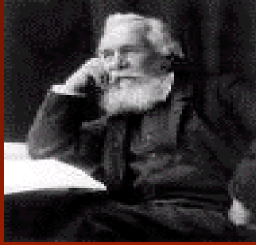


Ernst Haeckel (1834-1919)

Introduction

•Since the time of Von Baer and Haeckel, “evo-devo” biologists have debated the similarities and differences in development among species.

•Changes in developmental timing are thought to be important to morphological change during evolution.

•The question remains whether developmental pathways are conserved among different taxa. In other words, do all animals pass through similar stages of development?

•Here we evaluate differences in the developmental timing of one easily measured character shared by most higher organisms, time to first heartbeat (TFH).

•We extend the model of Gillooly et al. (2002) to test the hypothesis that differences in the TFH are controlled by metabolic rate, and thus by body size and temperature.

Model and Predictions

The model assumes the time to a fixed stage of development is controlled by metabolic rate. Thus, biological times (B) should be related to body mass and temperature as:

$$B = b_o M^{1/4} e^{E/kT}$$

given the size and temperature dependence of mass-specific metabolic rate shows the inverse size and temperature dependence. Here b_o is a metabolic normalization constant, M is body mass and $e^{E/kT}$ is the Boltzmann factor, where E is the average activation energy of metabolism (0.6-0.7 eV).

This leads to 2 predictions:

Prediction 1: A plot of the logarithm of the temperature-corrected time TFH versus the logarithm of body mass should show a slope of -0.25 given the mass dependence of metabolic rate

$$\ln(TFH/e^{E/kT}) = 0.25 \ln(M) + \ln(b_o)$$

Prediction 2: A plot of the logarithm of mass-corrected TFH versus 1/kT should show a slope of 0.6-0.7eV given the temperature dependence of metabolic rate.

$$\ln(TFH/M^{1/4}) = -0.65\ (1/kT) + \ln(b_o)$$

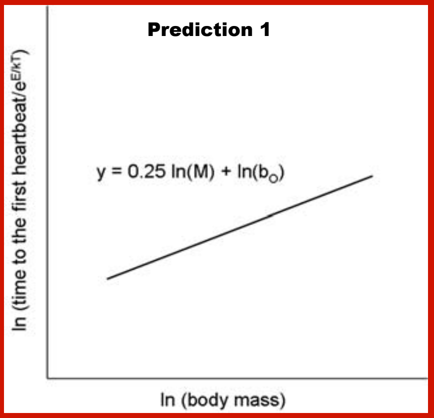
Methods

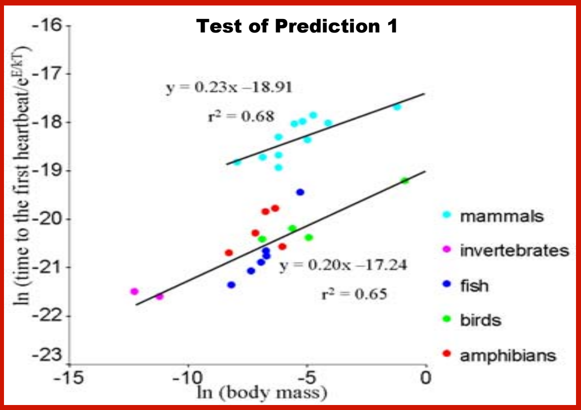
•Data on body size, temperature and TFH were gathered from the literature for several taxonomic groups (Mammals, Birds, Amphibians, Reptiles, Fish and Invertebrates)

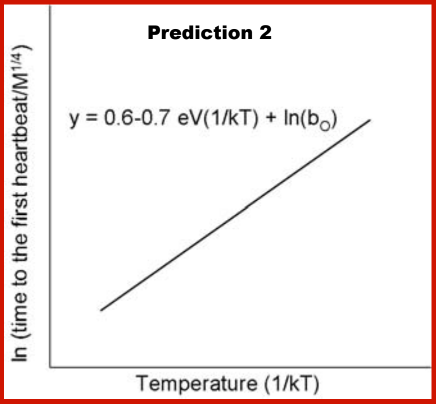
•Broad range of sizes (1.16 – 0.000047g) and temperature (3 – 38 °C) represented.

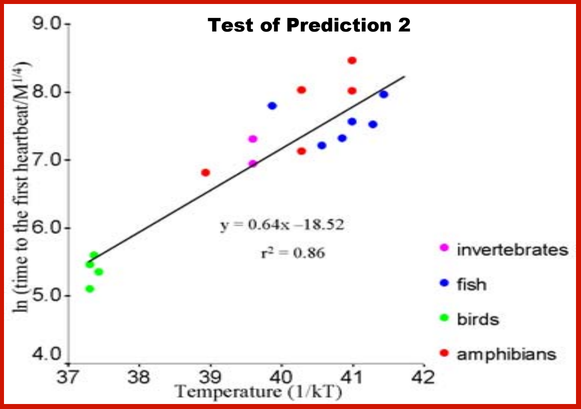
•All available data presented.

Results









Conclusions

•Results support the predicted body size and temperature dependence of the time to first heartbeat.

•Results indicate that, on average, a fixed amount of energy is required to reach this stage of differentiation, regardless of taxonomic affiliation.

•This is perhaps the first example of a highly conserved developmental stage. It is unclear whether other stages in development are similarly invariant.

•Perhaps most interesting, this work suggests that rates of gene expression responsible for heart development may also be controlled by metabolic rate and thus by body size and temperature.

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