Nearly everyone agrees that heterochrony has played some important role in human evolution. The exact nature of this role and, in particular, the type or types of heterochrony involved are not so well agreed upon. The notion of humans as neotenic apes has a certain poetic resonance (as depicted, e.g., in Aldous Huxley’s *After Many a Summer Dies the Swan* [1939]) and makes sense of the physical resemblance between infant apes and humans. On the other hand, humans are larger and longer lived than our closest relatives, the chimpanzees, implying some sort of hypermorphosis (Shea 1988; McKinney and McNamara 1991). Distinguishing between these options has been made difficult by the fact that the concept of heterochrony is used alternately as a catch-all description for any morphological change that involves a change in rate or timing (i.e., any morphological change) and as a specific theory that identifies a well-defined set of mechanistic transformations that may underlie some, but not all, morphological evolution.

Theoretical concepts in science allow us to represent the world in ways that draw our attention to fundamental relationships between different phenomena and give us a way to bring rigorous logic or mathematics to bear so as to discover new phenomena and direct further empirical research. If the concept of heterochrony is to serve as a theory in this sense, and I think that it should, then we must be able to distinguish between what is and is not heterochrony and have some notion of what it means biologically to make such a distinction. I addressed this elsewhere (Rice 1997) by showing that, if we define heterochrony as a uniform change in the rate or timing of some developmental process, with no other internal change to that process, then the traditional categories of heterochrony correspond to meaningful biological transformations that we can test for by comparing ontogenetic trajectories.

In this chapter, I develop a statistical test for heterochrony based on this definition and then apply this test to the trajectories for brain growth in humans and some other primates. The differences between human and chimpanzee brain growth are largely a result of uniform changes in rate and timing, thus heterochrony. Compared to other primates, though, humans and chimps show a novel phase of brain growth that is not a simple heterochronous modification of an ancestral trajectory. I also compare the overall growth of the body in humans and chimpanzees and show that heterochrony seems to be a factor here also, but with different kinds of transformations acting at different stages of growth.

**Analyzing Ontogenetic Trajectories**

Figure 7.1 shows the transformations that correspond to different types of heterochrony (see Rice 1997 for justification and derivation). I refer to two trajectories as being *commensurate* if we can superimpose one on the other by applying some combination of these transformations. If two trajectories are commensurate, then we can infer that the difference between the two growth processes *could* be accounted for by a uniform change in rate or timing.

By contrast, if two trajectories cannot be related by some combination of these transformations, then we can infer that there must have been some change in the nature of the interactions underlying the growth process, not just a change in the rate or timing of that process. This definition of the types of heterochrony is compatible with that of Alberch et al. (1979), with one modification. In Alberch et al., the endpoint of the trajectory was held fixed in time unless there was progenesis or hypermorphosis. I am allowing the endpoint to shift if the entire growth process is slowed down (neoteny) or sped up (acceleration). This will be important in the discussion of whole-body growth.

Because this definition assigns so much significance to the superposition of trajectories and because data for actual trajectories are likely to be noisy, we seek a statistical test to compare trajectories and potentially reject a hypothesis of heterochrony. Often, ontogenetic trajectories must be inferred from clouds of points, each of which represents a separate individual (Fig.
**Brain Growth**

The same side of the human body is four times more likely to develop brain tumors than the opposite side. This is in contrast to the normal distribution of brain tumors, which should ideally be evenly distributed. The asymmetry in brain tumor incidence could be due to genetic or environmental factors. The image shows a comparison of the growth of human and chimpanzee brain structures. The figure illustrates that human brains grow more rapidly than chimpanzee brains in certain regions.
Compromises of human and nonhuman evolution can be observed in the neuroplasticity of the human brain, which allows for the development of new neural connections and the modification of existing ones. This flexibility is crucial for the human species to adapt to changing environments and to learn new skills. However, the brain's plasticity also means that it can be vulnerable to damage or disease, as the neural circuits that support essential functions can be disrupted if not properly maintained. Therefore, understanding the balance between the brain's plasticity and stability is essential for developing strategies to protect and enhance brain health.
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In particular, the human brain follows a growth curve that is different from the one followed by animals. In humans, the brain grows in proportion to body size, whereas in animals, the brain grows in proportion to body weight. This difference is due to the fact that in humans, the brain is a smaller proportion of body weight than it is in animals.

Figure 7.8 shows a graph of body weight as a function of body size for humans and chimpanzees. The graph shows that the human brain grows more slowly than the chimpanzee brain, which is consistent with the fact that the human brain is a smaller proportion of body weight.

Figure 7.9 shows a graph of body size for humans and chimpanzees. The graph shows that the human brain is a smaller proportion of body weight than it is in chimpanzees.

The need for better performance-to-size ratios compared to flight, and superior efficiency in the use of resources is probably due to the fact that the human brain is a smaller proportion of body weight than it is in animals.
Consider a string of points each described either $\phi$ or $\psi$ above the line, or below. The state of each point is independent of the others, and each has two possible states. The joint probability $P(\phi, \psi)$ of finding the string $\phi \psi \phi \phi \psi \phi \psi$ is given by the product of the probabilities of each point. The total probability of all possible strings is the sum of the probabilities of each string.

**Appendix**

A morphofunctional model of macroevolution [Haldane, 1960] provides a more general theoretical framework for understanding the evolution of biological systems. This model considers the development of traits in populations as a consequence of the interaction between genetic and environmental factors. The model is based on the idea that the evolution of a trait is determined by the balance between selection and drift within a population. The model predicts that the evolution of traits will occur in a complex, non-linear manner, with the outcome dependent on a variety of factors, including the initial distribution of traits in the population, the strength of selection, and the level of genetic variation.

Morphofunctional evolution is a term used to describe the evolution of morphological traits in a population. It is based on the idea that the evolution of a trait is determined by the balance between selection and drift within a population. The model is based on the idea that the evolution of a trait is determined by the balance between selection and drift within a population. The model predicts that the evolution of traits will occur in a complex, non-linear manner, with the outcome dependent on a variety of factors, including the initial distribution of traits in the population, the strength of selection, and the level of genetic variation.

[Figure 1]: The transformation shown in Figure 1 corresponds to the traditional idea of the transformation axis. The movement of the function $f$ along the function $g$ corresponds to the traditional idea of the transformation axis. The movement of the function $f$ along the function $g$ corresponds to the traditional idea of the transformation axis. The movement of the function $f$ along the function $g$ corresponds to the traditional idea of the transformation axis. The movement of the function $f$ along the function $g$ corresponds to the traditional idea of the transformation axis.
The conditional probability, given that there was no previous of $x$, that is

\[
P(\mathcal{J} | \neg \mathcal{J}, x) = \frac{P(\mathcal{J} | x) P(x)}{P(x)}
\]

and

\[
P(x | \mathcal{J}, \neg \mathcal{J}) = \frac{P(\mathcal{J} | x) P(x)}{P(x)}
\]

The total number of possible sequences of $x$ with no two of $x$ which is

\[
P(\mathcal{J} | \neg \mathcal{J}, x) = \frac{P(\mathcal{J} | x) P(x)}{P(x)}
\]

and

\[
P(x | \mathcal{J}, \neg \mathcal{J}) = \frac{P(\mathcal{J} | x) P(x)}{P(x)}
\]
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