Volume II, Chapter 3

Developmental Critical Windows: Interaction Between Environment, Phenotype and Time

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Observable traits, or phenotypic characteristics, of an animal are a result of the interaction between the genome and environment. Differences in phenotypic traits between individuals induced by the environment, an indicator of phenotypic plasticity, may have immediate and long-term consequences for individuals, populations and species. During development, animals are often most responsive or susceptible to changes in their environment, and phenotypic plasticity can be particularly prevalent. Recognizing and understanding both the potential positive and negative consequences of plasticity is at the core of developmental physiological research. Classic developmental experiments, in which chronic exposures to different environmental conditions are used to examine phenotypic variability, are useful for assessing the importance of the environment on developmental physiology. However, it is increasingly apparent that the way in which the environment influences an animal’s physiology may differ not just across a species’ lifetime, but also within a species’ ontogeny. Periods of development during which an animal may show greater likelihood of phenotypic changes are termed ‘developmental critical windows’ or ‘sensitive periods’. The terms ‘sensitive period’ or ‘critical period’ first appeared in the medical literature in the 1970’s and 80’s, particularly in relation to the required developmental processes that occur at certain times during human development, such as sensory maturation and language acquisition. Critical windows continue to be a focus for the medical field in research concerning the developmental origins of human disease, and critical windows have also become a fundamental concept of comparative physiology and animal toxicology. Across animal taxa, experiments that utilize exposure to particular environmental, chemical or pharmacological stressors at certain time points of development are used as a means to detect and understand critical windows during development. This chapter examines the emergence of critical windows as an important physiological concept, predominantly in respect to environment-development interactions. How critical windows are defined and studied is discussed using examples from the literature that span model and non-model invertebrates and vertebrates. Future directions for critical windows research are also considered. As our knowledge of developmental phenotypic plasticity and critical windows grows, how we approach their study must also evolve. Critical window experimental designs are increasing in complexity, and this chapter reviews the practicality and effectiveness of various designs. Experiments often expose a developing animal to a single stressor dose during a few windows of development, whereas detailed experiments may implement a more detailed experimental design in which multiple exposure windows and stressor doses are utilized to examine the extent of phenotypic change. Understanding periods of phenotypic plasticity during development is not only vital for understanding developmental physiology in its own right, but also has potential implications for appreciating the future challenges faced by animals during development, such as global climate change and toxicology in relation to human industrial processes and waste. Examination of the interaction between the environment and physiology of an animal during development, and during developmental critical windows, will be vital for assessing the future success of species in a changing world.