Environmental Influences on Gene Expression

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Internal and external environmental factors, like gender and temperature, influence gene expression.

The expression of genes in an organism can be influenced by the environment, including the external world in which the organism is located or develops, as well as the organism's internal world, which includes such factors as its hormones and metabolism. One major internal environmental influence that affects gene expression is gender, as is the case with sex-influenced and sex-limited traits. Similarly, drugs, chemicals, temperature, and light are among the external environmental factors that can determine which genes are turned on and off, thereby influencing the way an organism develops and functions.

Sex-Influenced and Sex-Limited Traits

Sex-influenced traits are those that are expressed differently in the two sexes. Such traits are autosomal, which means that the genes responsible for their expression are not carried on the sex chromosomes. An example of a sex-influenced trait is male-pattern baldness. The baldness allele, which causes hair loss, is influenced by the hormones testosterone and dihydrotestosterone, but only when levels of the two hormones are high. In general, males have much higher levels of these hormones than females, so the baldness allele has a stronger effect in males than in females. However, high levels of stress can lead to expression of the gene in women. In stressful situations, women's adrenal glands can produce testosterone and convert it into dihydrotestosterone, which can result in hair loss.

Sex-limited traits are also autosomal. Unlike sex-influenced traits, whose expression differs according to sex, sex-limited traits are expressed in individuals of only one sex. An example of a sex-limited trait is lactation, or milk production. Although the genes for producing milk are carried by both males and females, only lactating females express these genes.

Drugs and Chemicals

The presence of drugs or chemicals in an organism's environment can also influence gene expression in the organism. Cyclops fish are a dramatic example of the way in which an environmental chemical can affect development. In 1907, researcher C. R. Stockard created cyclopean fish embryos by placing fertilized *Fundulus heteroclitus* eggs in 100 mL of seawater mixed with approximately 6 g of magnesium chloride. Normally, *F. heteroclitus* embryos feature two eyes; however, in this experiment, half of the eggs placed in the magnesium chloride mixture gave rise to one-eyed embryos (Stockard, 1907).

A second example of how chemical environments affect gene expression is the case of supplemental oxygen administration causing blindness in premature infants (Silverman, 2004). In the 1940s, supplemental oxygen administration became a popular practice when doctors noticed that increasing oxygen levels converted the breathing pattern of premature infants to a "normal" rhythm. Unfortunately, there is a causal relationship between oxygen administration and retinopathy of prematurity (ROP), although this relationship was unknown at the time; thus, by 1953, ROP had blinded approximately 10,000 infants worldwide. Finally, in 1954, a randomized clinical trial identified supplemental oxygen as the factor causing blindness. Complicating the issue is the fact that too little oxygen results in a higher rate of brain damage and mortality in premature infants. Unfortunately, even today, the optimal amount of oxygenation necessary to treat premature infants while completely avoiding these complications is still not clear.

Yet another example of the way in which chemicals can alter gene expression involves thalidomide, a sedative, antiemetic, and nonbarbiturate drug that was first manufactured and marketed during the mid-1950s. While thalidomide has no discernable effect on gene expression and development in healthy adults, it has a profoundly detrimental effect on developing fetuses. When the drug was first created, however, its impact on fetuses was not known. Moreover, because of its apparent lack of toxicity in adult human volunteers, thalidomide was marketed as the safest available sedative of its time and rapidly became popular in Europe, Australia, Asia, and South America for countering the effects of morning sickness. (In the United States, the drug failed to receive Food and Drug Administration approval because its side effects included tingling hands and feet after long-term administration, which led to concerns that the drug might be associated with neuropathy.) Not until 1961 did Australian researcher William McBride and German researcher Widukind Lenz independently report that thalidomide was a teratogen, meaning that its use was associated with birth defects. Another study associated thalidomide use with neuropathies. Sadly, the drug was withdrawn too late to prevent severe developmental deformities in approximately 8,000 to 12,000 infants, many of whom were born with stunted limb development. Interestingly, despite the fact that thalidomide is dangerous during embryonic development, the drug continues to be used in certain instances yet today. For example, it has therapeutic potential in treating leprosy, and in recent years, it has also been used to treat cancers and enhance the effectiveness of cancer vaccines (Bartlett *et al.*, 2004; Fraser, 1988).

Temperature and Light

Figure 1: A pigment gene is influenced by temperature. Gene C controls fur pigmentation in Himalayan rabbits. Because the gene is active when environmental temperatures are between 15 and 25°C, the rabbit reared at 20°C (left) has pigmentation on its ears, nose, and feet, where its body loses the most heat. The rabbit reared at temperatures above 30°C (right) has no fur pigmentation, because gene C is inactive at these higher temperatures.

In addition to drugs and chemicals, temperature and light are external environmental factors that may influence gene expression in certain organisms. For example, Himalayan rabbits carry the C gene, which is required for the development of pigments in the fur, skin, and eyes, and whose expression is regulated by temperature (Sturtevant, 1913). Specifically, the C gene is inactive above 35°C, and it is maximally active from 15°C to 25°C. This temperature regulation of gene expression produces rabbits with a distinctive coat coloring. In the warm, central parts of the rabbit's body, the gene is inactive, and no pigments are produced, causing the fur color to be white (Figure 1). Meanwhile, in the rabbit's extremities (i.e., the ears, tip of the nose, and feet), where the temperature is much lower than 35°C, the C gene actively produces pigment, making these parts of the animal black.

Light can also influence gene expression, as in the case of butterfly wing development and growth. For example, in 1917, biologist Thomas Hunt Morgan conducted studies in which he placed *Vanessa urtica* and *Vanessa io* caterpillars under red, green, or blue light, while other caterpillars were kept in the dark. When the caterpillars developed into butterflies, their wings showed dramatic differences. Exposure to red light resulted in intensely colored wings, while exposure to green light resulted in dusky wings. Blue light and darkness led to paler colored wings. In addition, the *V. urtica* butterflies reared under blue light and *V. io* butterflies reared in the dark were larger than the other butterflies.

As these examples illustrate, there are many specific instances of environmental influences on gene expression. However, it is important to keep in mind that there is a very complex interaction between our genes and our environment that defines our phenotype and who we are.

References and Recommended Reading

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