Hardy-Weinberg Equilibrium

Chapter 23
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Hardy-Weinberg Equilibrium

• Definition: allele frequencies in a population remain constant from generation to generation (genetic equilibrium)
  – Population allele and genotype frequencies remain constant from generation to generation unless they are acted upon by forces other than normal genetics (excluding mutations)
• At genetic equilibrium, THERE IS NO EVOLUTION
• In order for equilibrium to occur, the factors that normally change gene frequencies [cause evolution] do not occur

Conditions for Hardy-Weinberg Equilibrium
1. All traits are selectively neutral (no natural selection).
2. Mutations do not occur.
3. The population must be isolated from other populations (no gene flow).
4. The population is extremely large (no genetic drift).
5. Mating is random.

If at least one of these conditions is NOT met, then the population is EVOLVING!

Allele Frequency

• Allele frequencies – the % of the gene pool that consists of dominant alleles (p) and recessive alleles (q)
• Allele frequencies: gene with 2 alleles (p, q)
  – p = frequency of dominant allele (A)
  – q = frequency of recessive allele (a)
  – P + q = 1
    • 1 - p = q
    • 1 - q = p
  • 100% of alleles must be dominant or recessive

Genotype Frequency

• Genotype frequencies – the % of the population that consists of homozygous dominant (AA), heterozygous (Aa) and homozygous recessive (aa) individuals
• Genotypic frequencies: 3 genotypes (AA, Aa, aa)
  – p² + 2pq + q² = 1
    • 100% of individuals must be one of the three genotypes
    • p² = AA (homozygous dominant)
    • 2pq = Aa (heterozygous)
    • q² = aa (homozygous recessive)
    • In equilibrium, it should = 1; if it does not, then the population is evolving

Hardy-Weinberg Principle

• Genetic equilibrium is determined by evaluating the following values:
  – Allele frequencies for each allele (p, q)
  – Frequency of homozygotes (p², q²)
  – Frequency of heterozygotes (pq + qp = 2pq)
• Also, the following two equations hold:
  – p + q = 1 (all alleles sum to 100%)
  – p² + 2pq + q² = 1 (all individuals sum to 100%)
Summary

• $p^2 = \%$ of population that is homozygous dominant ($p^2 = 2$ A alleles)
• $2pq = \%$ of population that is heterozygous
  – Note that both of these genotypes express the dominant trait under complete dominance
  – $p^2 + 2pq = \%$ of population expressing dominant trait (unsolvable)
• $q^2 = \%$ of population that is homozygous recessive

But Wait, There’s More!

• You can also determine the frequency (or percentages) of individuals with the homozygous dominant and heterozygous condition.
  – $2pq = (2)(0.6)(0.4) = 0.48$ or 48% = heterozygotes
  – $p^2 = (0.6)(0.6) = 0.36$ or 36% = homozygous dominant

However...

• In most natural populations, the conditions of Hardy-Weinberg equilibrium are NOT obeyed
• These calculations serve as a starting point that reveal...
  – How allele frequencies are changing
  – Which equilibrium conditions are being violated
  – What mechanisms are driving the evolution of a population

Be Cautious!

• 1% = 0.01
• 10% = 0.10
• 100% = 1.0

• Square root of 0.01 = 0.1
• Square root of 0.04 = 0.2

Strategies

1. If you are given the genotypes (AA, Aa, aa), calculate $p$ and $q$ by adding up the total # of A and a alleles.
2. If you know phenotypes, then use “aa” to find $q^2$, and then $q$. ($p = 1 - q$)
3. To find out if population is evolving, calculate $p^2 + 2pq + q^2$.
   – If in equilibrium, it should = 1.
   – If it DOES NOT = 1, then the population is evolving!

Example of HWE

• Suppose a plant population consists of 84% plants with red flowers and 16% white flowers.
• Assume the red allele (R) is dominant and the white allele (r) is recessive. Using the previous notation and converting percentages to decimals...
  – $q^2 = 0.16$ = white flowered plants (rr trait)
  – $p^2 = 0.84$ = red flowered plants (RR and Rr trait)
• To determine the allele frequency of the white flower allele, calculate $q$ by finding the square root of $q^2$.
  – $q = \sqrt{0.16} = 0.4$
• Since $p + q = 1$, $p$ must equal 0.6
• Determine the percent of the population that is homozygous dominant if the percent of the population that is homozygous recessive is 16%.
  - Homozygous recessive = q^2 = 16
  - Therefore, q^2 = .16 and q = 0.4
  - If q = 0.4, then p = 0.6
  - Therefore, the percentage of the population that is homozygous dominant is p^2 = .36 = 36%

• Determine the percent of the population that is hybrid if the allelic frequency of the recessive trait is 0.5.
  - In this example, you are given the value of q (not q^2). You only need to subtract from 1 to get the value of p.
  - If p + q = 1 and q = 0.5; then p + 0.5 = 1
  - Since both p = 0.5 and q = 0.5, the percentage of the population that is hybrid is 2pq = 2(0.5)(0.5) = 50%

Calculating Hardy-Weinberg Problems
• If 9% of the population has blue eyes, what percent of the population is hybrid for brown eyes? Homozygous for brown eyes?
  - Trait for blue eyes is homozygous recessive – bb is represented by q^2.
  - q^2 = 9%; convert to decimal: q^2 = 0.09
  - To solve for q, the square root of .09 = 0.3
  - Since p + q=1, if q = 0.3, p = 0.7
  - The hybrid brown condition is represented by 2pq, so...
  - To solve for the percent of the population that is hybrid, substitute values for 2(p)(q). The percentage of the population that is hybrid brown is 2(0.7)(0.3) = 42%
  - Homozygous dominant is represented by p^2. The percentage of the population that is homozygous brown is p^2 = (.7)^2 = 49%

Practice
• If 10% of the alleles in a gene pool are dominant, what % of the individuals are
  - Heterozygous?
  - Homozygous recessive?
  - Expressing the dominant trait?

• If 16% of the population expresses the recessive trait
  - What are p and q?
  - What % of individuals are homozygous dominant?

Practice
• 64% of the population expresses the dominant trait
  - Find p and q and the % of the population that is heterozygous

• The scarlet tiger moth has the following genotypes. Calculate the allele and genotype frequencies (%) for a population of 1612 moths.
  - AA = 1469  Aa = 138  aa = 5
  - Allele Frequencies:
    - A (aka p) =
    - a (aka q) =

  - Genotypic Frequencies:
    - AA (aka p^2) =
    - Aa (aka 2pq) =
    - aa (aka q^2) =

Practice