Genetic correlation; genotype x environment interaction
Overview

- Relationships between traits
- Indirect selection
- Genotype x environment interaction
Relationships between traits
Relationships between traits are easily observed

- Animals with higher growth rate tend to be fatter
- Animals with higher birth weight tend to have higher weaning weight
- Animals with lower body weight tend to have smaller litter sizes
Relationships between traits occur due to:

- Gene is pleiotrophic (same gene influences the two traits)
- Genes for each trait are tightly linked (genes located close together on chromosome)
- Environmental conditions affecting both traits
What does the relationship look like?

- Graph of trait \( y \) versus \( x \)
  - Positive association
  - No association
  - Negative association

- See page 52 Simm

(sorry can’t draw pictures here as am typing with one arm as the other is broken)
Describing the association between traits

The direction and strength of the association between traits can be described by two related parameters – the regression coefficient \( b \) and the correlation coefficient \( r \).
Describing associations

- **Covariance**

- **Regression** - measures extent which changes in one trait are associated with changes in another, in units of measurement

- **Correlation** - measures association between traits, but on scale -1 to 1, rather than units of measurement

\[
\text{Cov}(X,Y) = \frac{\sum (X - \bar{X})(Y - \bar{Y})}{n - 1}
\]

\[
b_{Y,X} = \frac{\text{Cov}_{x,y}}{V_x}
\]

\[
r_{X,Y} = \frac{\text{Cov}_{x,y}}{\sigma_x \sigma_y}
\]
More on regression

- $b_{pwwt,bwt} = 2.125$
- 1 kg change in birth weight (bwt) is expected to result in a 2.125 kg change in post-weaning weight (pwwt) on average

![Sheep data graph](image)
More on correlation

- **Express relationship in SD units**
  - e.g. \( r = -0.5 \) then animals +1 SD unit in one trait are expected to be -0.5 SD units on average in second trait

- **Look at sign**
  - Tells whether association is +ve, 0, or -ve

- **Look at size**
  - Tells how closely individual points are clustered around the line drawn through them
  - If correlation is +1 or -1 then all points are on line
Example

\[ Y = [2,4,6,8,10] \quad V_Y = 10 \quad \sigma_Y = 3.16 \]
\[ X = [1,2,3,4,5] \quad V_X = 2.5 \quad \sigma_X = 1.58 \]

\[ \text{Cov}_{Y,X} = 5 \]

\[ b = \frac{\text{Cov}_{Y,X}}{V_X} = \frac{5}{2.5} = 2 \]

2 units change in \( Y \) for every 1 unit change in \( X \)

\[ r = \frac{\text{Cov}_{Y,X}}{(\sigma_X \times \sigma_Y)} = \frac{5}{(1.58 \times 3.16)} = 1 \]

1 stddev change in \( Y \) for every 1 stddev change in \( X \)
P, G & E associations
- **Phenotypic correlations** $r_p$ measure association between observed performance.

- **Genetic correlations** $r_A$ measure association between breeding values.
  - $r_A$ not equal to zero generally implies pleiotrophy (may be +ve or -ve).

- **Environmental correlations** $r_E$ measure association between environmental affect on traits.
  - May be +ve, e.g., feed affects both weight & fat, or -ve.
Recall
\[ V_P = V_A + V_E \]

Similarly
\[ \text{Cov}_P = \text{Cov}_A + \text{Cov}_E \]

(note that b and r are *not* similarly additive)

- Cov$_A$ and Cov$_E$ can differ
  - e.g. muscle depth and fertility may have no genetic covariance (and thus no genetic correlation),
    but can have a positive environmental covariance (and thus a positive environmental correlation)
Use of correlations

- Predict change in one trait when selecting on another
- Construct selection indexes involving multiple traits
- Provide an additional information source in terms of predicting breeding values
Genetic correlation & indirect selection
What is indirect selection

- Selecting on trait x when you are interested in the correlated response in trait y

- For example
  - selecting on muscle depth when the breeding objective is muscle area
  - selecting on fecal egg count when the breeding objective is disease resistance
  - selecting on scrotal circumference when the breeding objective is fecundity
Why use indirect selection

- It may be possible to make faster genetic progress in trait y by selecting on trait x, if the traits have a high genetic correlation and trait x is more heritable.

- Want to select for trait y but it is difficult or expensive to measure. If trait x is genetically correlated to trait y, it may be more economical / practical to select on trait x.

- Correlated trait can be measured earlier, resulting in shorter generation interval.
Predicting the correlated response

We can predict breeding values for trait $y$ from breeding values for trait $x$.

\[ \hat{A}_y = b_{A_y|A_x} A_x \]
Predicting the correlated response

- Correlated response in trait $y$
  - from before
  \[
  \hat{A}_y = b_A A_x
  \]
  - similarly
  \[
  CR_y = b_A R_x
  \]

Correlated response ($CR_y$) = response in trait $y$ due to selection on trait $x$. 
Given

\[ CR_y = b_A R_x \]

\[ R_x = i_x h_x^2 \sigma_{px} \]

from derivation

\[ CR_y = i_x r_A h_x h_y \sigma_{py} \]

correlated response in trait y when selecting on trait x

selection intensity \((i)\) for trait you are selecting on

phenotypic standard deviation for trait with correlated response
$CR_Y / R_Y$

- Response for indirect selection for a trait relative to response for direct selection for a trait

\[
CR_Y/R_Y = \frac{i_x r_A h_x h_y \sigma_{py} / L_x}{i_y h_y^2 \sigma_{py} / L_y} = \frac{i_x h_x L_y}{i_y h_y L_x} r_A
\]
Example

- Objective is to increase weight in Atlantic Salmon
- ? select on weight directly, or select on length with a correlated response in weight

- h² weight = 0.09
- h² length = 0.16
- r_A = 0.95

\[
\frac{CR_y}{R_y} = \frac{i_x h_x L_y}{i_y h_y L_x} \quad r_A = \frac{h_x r_A}{h_y} = \frac{\sqrt{0.16}}{\sqrt{0.09}} = 0.95 = 1.27
\]

selecting on length gives 27% more response in weight then selecting on weight directly (length is more heritable and correlation is strong)

- ? could you still select on length if r was negative
Example

- Objective is to increase weight in Atlantic Salmon
- ? select on weight directly, or select on length with a correlated response in weight

- $h^2$ weight = 0.39
- $h^2$ length = 0.16
- $r_A = 0.95$

$$\frac{CR_Y}{R_Y} = \frac{i_x h_x L_y}{i_y h_y L_x} r_A = \frac{h_x}{h_y} r_A = \frac{\sqrt{0.16}}{\sqrt{0.39}} 0.95 = 0.608$$

selecting on length gives less response in weight than selecting on weight directly (weight is more heritable)
Example

- Objective is to increase weight in Atlantic Salmon
- ? select on weight directly, or select on length with a correlated response in weight

- $h^2$ weight = 0.09
- $h^2$ length = 0.16
- $r_A = 0.15$

\[
\frac{CR_Y}{R_Y} = \frac{i_x h_x L_y}{i_y h_y L_x} r_A = \frac{h_x}{h_y} r_A = \frac{0.16}{\sqrt{0.09}}
\]

selecting on length gives less response in weight then selecting on weight directly (genetic correlation is weak)
Correlated response and indirect selection summary

- If traits x and y are genetically correlated, selecting on trait x will produce a correlated response in trait y.

- Under some circumstances greater response in trait y can be achieved through indirect selection on trait x.
Genotype x environment (G x E) interaction
Genotype x environment (G x E) interaction

- Occurs if
  - different breeds (genotypes) rank differently in different environments
  - difference between breeds (genotypes) is smaller or larger in different environment

\[ i.e. \text{the genetic correlation (} r_A \text{) between the same trait expressed in different environments is} < 1 \]
G x E interaction

G x E: breeds rank differently

G x E: relative merit differs
Example: yearling weight in beef cattle (hypothetical)

<table>
<thead>
<tr>
<th>Breed</th>
<th>Temperate</th>
<th>Tropical</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bos. Taurus</td>
<td>340</td>
<td>230</td>
<td>285</td>
</tr>
<tr>
<td>Bos. Indicus</td>
<td>290</td>
<td>250</td>
<td>270</td>
</tr>
<tr>
<td>Average</td>
<td>315</td>
<td>240</td>
<td>277.5</td>
</tr>
</tbody>
</table>

Effect of breed depends on which environment the animals are performing.
Bos. Taurus in a temperate environment are expected to perform $277.5 + 7.5 + 37.5 = 322.5$ Kg, however this is not the case due to G x E interaction.

<table>
<thead>
<tr>
<th></th>
<th>Temperate</th>
<th>Tropical</th>
<th>Average</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bos. Taurus</td>
<td>340</td>
<td>230</td>
<td>285</td>
<td>+7.5</td>
</tr>
<tr>
<td>Bos. Indicus</td>
<td>290</td>
<td>250</td>
<td>270</td>
<td>-7.5</td>
</tr>
<tr>
<td>Average</td>
<td>315</td>
<td>240</td>
<td></td>
<td>277.5 Kg</td>
</tr>
<tr>
<td>Effect</td>
<td>+37.5</td>
<td>-37.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Importance of G x E interactions

- Has been studies for a number of production systems

- General conclusion is that it is of little practical importance unless $r_A < 0.80$
G x E interaction summary

- Occurs when effect of genotype depends on the environment in which animals are performing.
- Can change rank or relative merit of the breed averages (and similarly individuals within the breed).