Heritability and environmentality of WISC subscales

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The WISC and other intelligence tests

Intelligence tests

Uses

- For selection into some schools, universities, and jobs
  - e.g. some UK grammar schools use verbal and/or non-verbal reasoning tests
- For diagnosis of conditions including learning difficulties, brain damage, Alzheimer's disease
  - May involve calculation of IQ, comparison of scores on intelligence tests with school achievement, or comparison of scores on different subtests
- In academic research into cognitive ability

The Wechsler Intelligence Scales for Children

- Version of the Wechsler Adult Intelligence Scales (WAIS) for children
- Several revisions over time, but subtests remain very similar
- Originally, designed to measure Verbal and Performance (non-verbal) IQs as well as Full Scale IQ
- More recently, four indexes developed
- One of the most widely used intelligence tests

Verbal comprehension	Perceptual organisation	Working memory	Processing speed
Vocabulary	Picture completion	Arithmetic	Coding
Similarities	Block design	Digit span	Symbol search
Information	Matrix reasoning	Letter-Number sequencing	

Information

Answer questions testing general knowledge, e.g. “How many days are there in a week?”

- One of the Verbal tests
- Measures learned knowledge
- Relatively little affected by brain dysfunction or aging

All information about WISC subtests from Tulsky et al. (2003)

Comprehension

Answer questions testing knowledge and judgement in social and practical situations, e.g. “What would you do if you cut your finger?”

- One of the Verbal tests
- May possibly also measure social intelligence

Vocabulary

Give definitions of words, e.g. "What is a bicycle?"

- One of the Verbal tests
- Measures learned knowledge
- Has highest correlation with g of all the subtests
- Relatively little affected by brain dysfunction or aging

Digit Span

Repeat a sequence of digits read out by the examiner, in the same order or in reverse order

- One of the Verbal tests
- Has one of the lowest correlations with g
- Low scores can indicate problems with attention

Picture Arrangement

Put picture cards in correct order to form a story

- One of the Performance tests
- Correlates fairly highly with the Verbal subtests
- May possibly measure social judgement

Block Design

Use cubes with red, white, and red and white sides to recreate a presented design

- One of the Performance tests
- Timed test
- Correlates highly with *g*
- Affected by aging

Coding

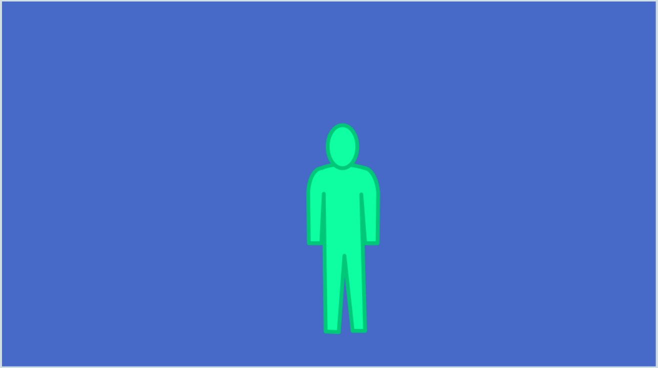
Add particular marks to particular shapes: one vertical line inside every star, two horizontal lines inside every circle, one horizontal line inside every triangle, a circle inside every cross, and two vertical lines inside every square

- One of the Performance tests
- Useful as part of diagnosis of many conditions since several factors influence scores (motor coordination, short-term memory, visual perception, speed and accuracy)

Heritability and environmentality

Genetic and environmental effects

We can partition differences between individuals into those that are due to differences in genes and those that are due to differences in the environment experienced



Environmental differences can in theory be further partitioned

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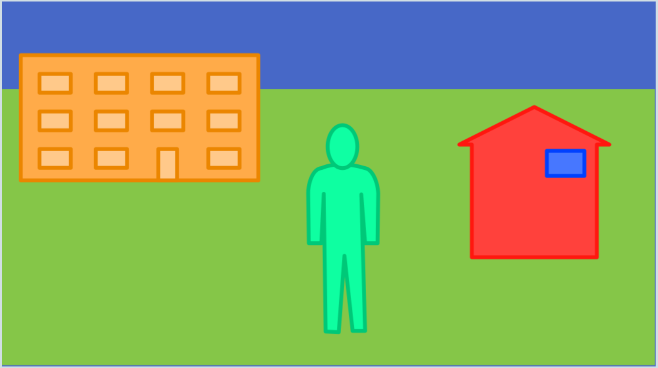
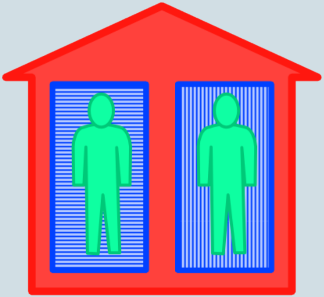


Environmental differences can in theory be further partitioned

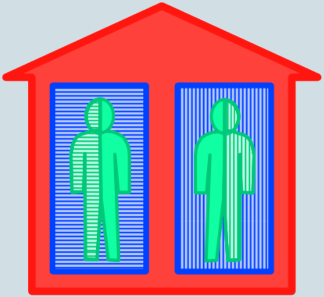
Measuring heritability

Different genetic relatedness of identical and non-identical twins allows identification of genetic, shared environmental, and non-shared environmental effects. (We assume identical and non-identical twins experience equally similar environments).

Identical twins



Non-identical twins



Differential heritability and environmentality

The contributions of genetics and the environment to differences between individuals may depend on the environment

Gene-environment interaction

The effect of a gene depends on the environment an individual experiences

Bio-ecological model

Some genes predispose individuals to attain high scores, but can only fully operate in beneficial environments Bronfenbrenner & Ceci (1994)

Diathesis-stress model

Some genes protect individuals against the effects of poor environments and allow them to still attain high scores
e.g. Jenkins et al. (2008)

Differential heritability and environmentality

The contributions of genetics and the environment to differences between individuals may depend on the environment

Environment-environment interaction

The effect of an unmeasured environmental factor depends on another aspect of the environment an individual experiences

Bio-ecological model

Some environmental factors predispose individuals to attain high scores, but only have their full effect in otherwise beneficial environments Bronfenbrenner & Ceci (1994)

Diathesis-stress model

Some environmental factors allow individuals to cope with poor environments and still attain high scores;
or individuals can cope with the effects of just one adverse environmental factor but not with several e.g. Jenkins et al. (2008)

Bio-ecological model

Perhaps some plants have genes for height that can only work where water is plentiful

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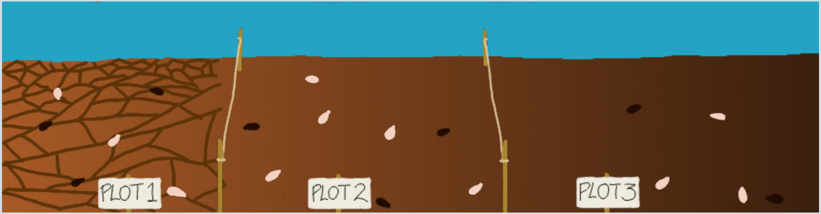

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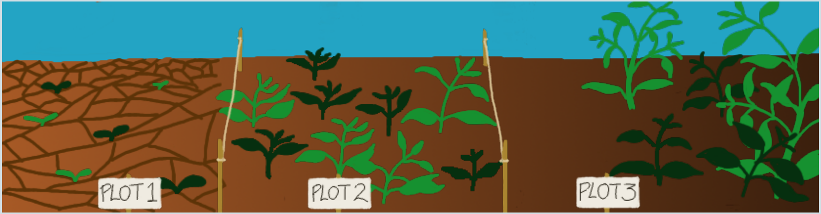

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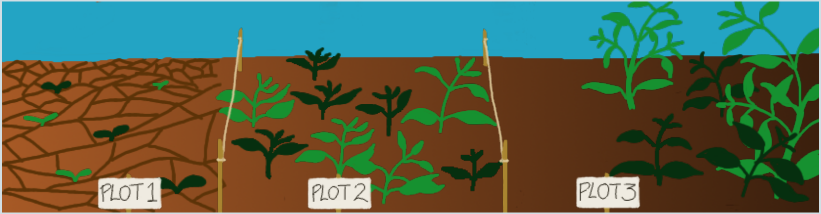

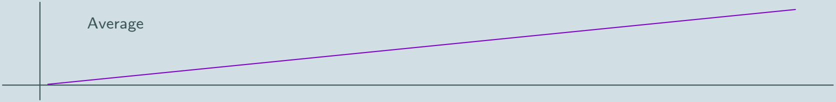

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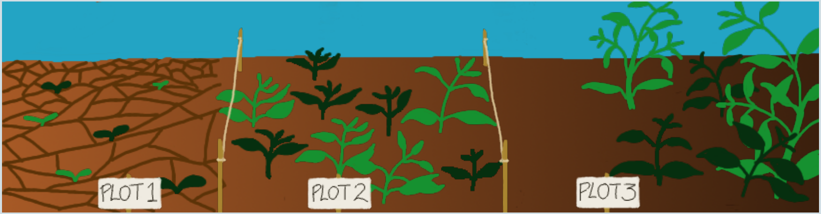

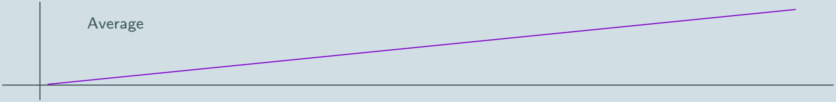

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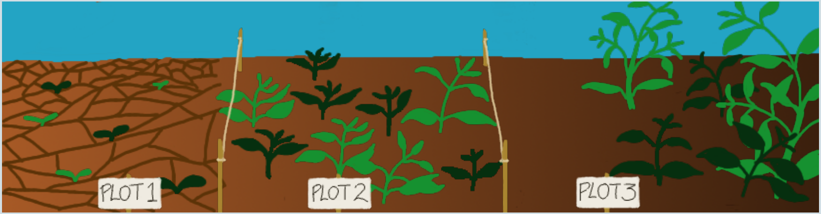

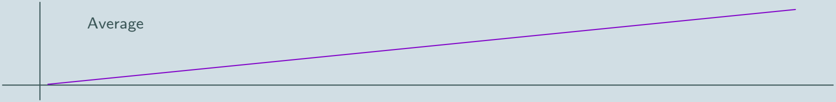

Perhaps some children have genes that predispose them to score well, but these can only operate in beneficial environments

Diathesis-stress model

Perhaps some plants have genes that let them thrive even in a drought

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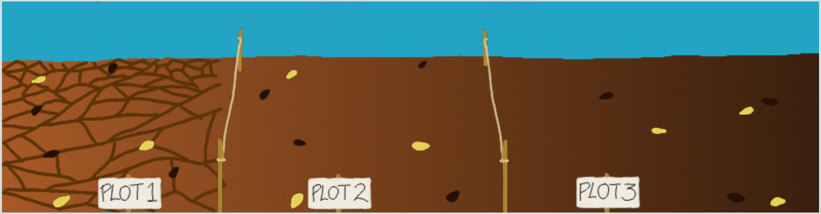

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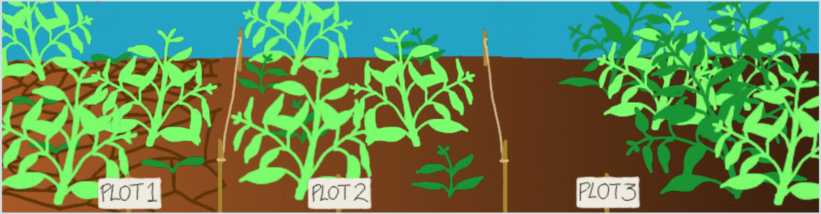

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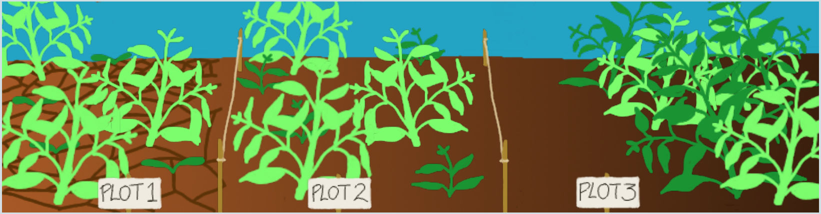

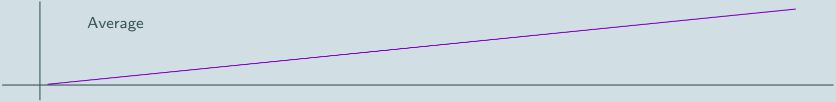

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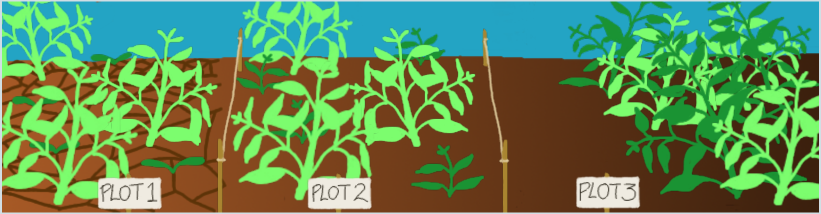

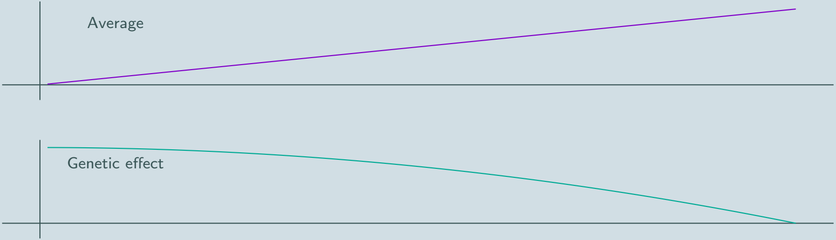

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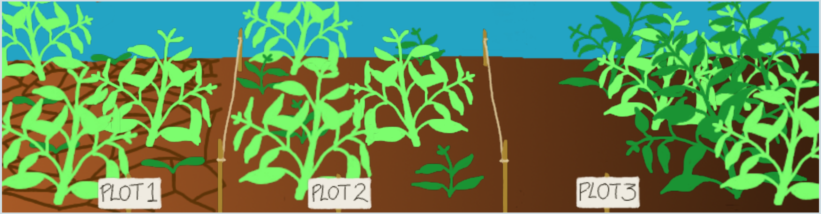

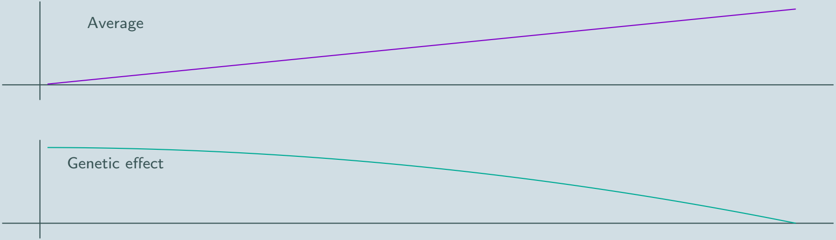

Perhaps some children have genes that let them score well despite poor environments

Differential variability

Perhaps genes or environmental factors are distributed differently in different locations

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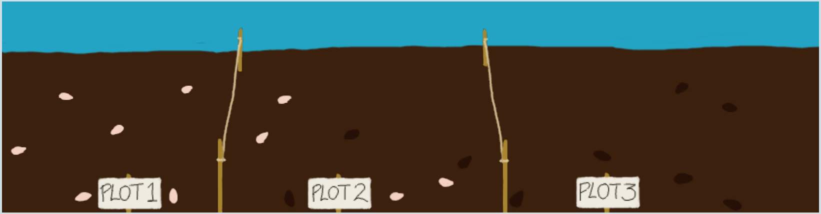

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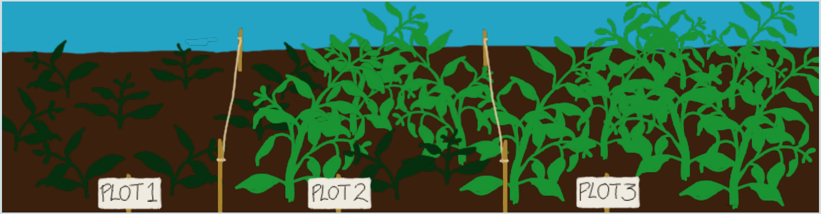

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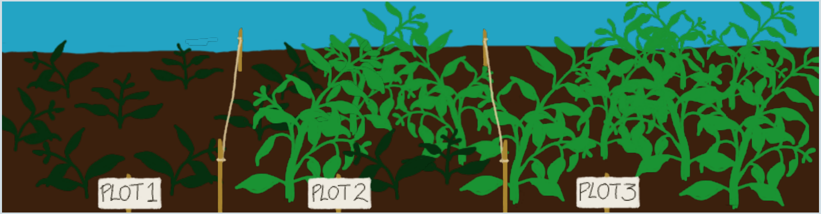

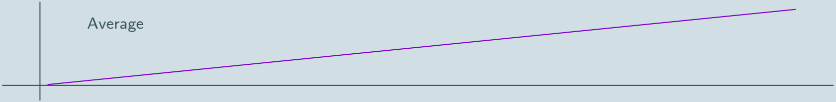

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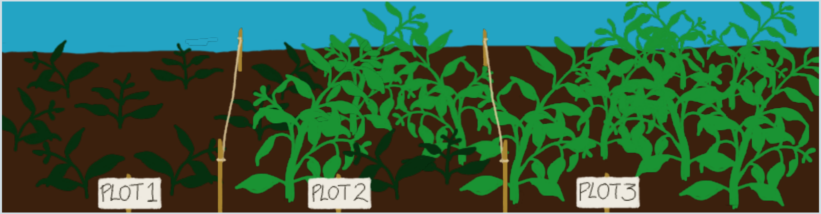

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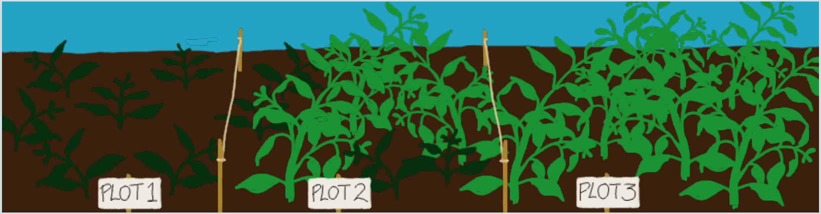

Perhaps the distribution of genes or unmeasured environmental factors depends on some environmental factor e.g. income

Models

Genetic model

We can exploit the different genetic relatedness of identical (MZ) and non-identical (DZ) twins to decompose variation in an outcome into a genetic, a shared environmental, and a non-shared environmental component

Model

$$y_{ij} = \beta_0 + \beta_1 x_j + c_j + a_{ij} + e_{ij}$$

$$c_j \sim \mathrm{N}(0, \sigma_C^2)$$
$$a_{ij} \sim \mathrm{N}(0, \sigma_A^2)$$
$$e_{ij} \sim \mathrm{N}(0, \sigma_E^2)$$

$$\mathrm{cov}(g_{1j}, g_{2j}) = r_j \sigma_G^2$$

$$r_j = \begin{cases} 1 & \text{MZ twins} \\ 0.5 & \text{DZ twins} \end{cases}$$

Differential heritability and environmentality

We can allow these components to change with some x

$$y_{ij} = \beta_0 + \beta_1 x_j + c_{0j} + c_{1j} x_j + a_{0ij} + a_{1ij} x_j + e_{0ij} + e_{1ij} x_j$$

$$\begin{bmatrix} c_{0j} \\ c_{1j} \end{bmatrix} \sim \mathrm{N}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma^2_{C0} & \\ \sigma_{C01} & \sigma^2_{C1} \end{bmatrix} \right)$$

$$\begin{bmatrix} a_{0ij} \\ a_{1ij} \end{bmatrix} \sim \mathrm{N}\left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma^2_{A0} & \\ \sigma_{A01} & \sigma^2_{A1} \end{bmatrix} \right)$$

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$$\mathrm{cov}(a_{01j}, a_{02j}) = r_j \sigma^2_{A0}$$

$$\mathrm{cov}(a_{11j}, a_{12j}) = r_j \sigma^2_{A1}$$

$$\mathrm{cov}(a_{01j}, a_{12j}) = r_j \sigma_{A01}$$

$$\mathrm{cov}(a_{11j}, a_{02j}) = r_j \sigma_{A01}$$

Data

Data

National Collaborative Perinatal Project

- 12 different urban sites in the US participated
- Pregnancies between 1959 and 1966
- At each site, all pregnant women or a random selection of them sampled
- For sampled women, subsequent pregnancies within study timeframe also included
- c. 50,000 pregnancies of which c. 600 twin pairs (c. 500 with zygosity information)
- We look at subscales of the Wechsler Intelligence Scales for Children (WISC), administered at age 7
- We also have information on SES at birth and at age 7 (education, occupation, income)

Measures: socioeconomic status variables

- Parental education, occupation and income available when children are born and at age 7
  - Used measures at age 7
  - Also ran with education and occupation at birth; not presented here but results were similar
- Which parent used varies from family to family
- Income adjusted to be comparable across all enrollment dates
- Although categorical in their original form, the original researchers provided recodings of these variables intended to be treated as continuous and we use these here

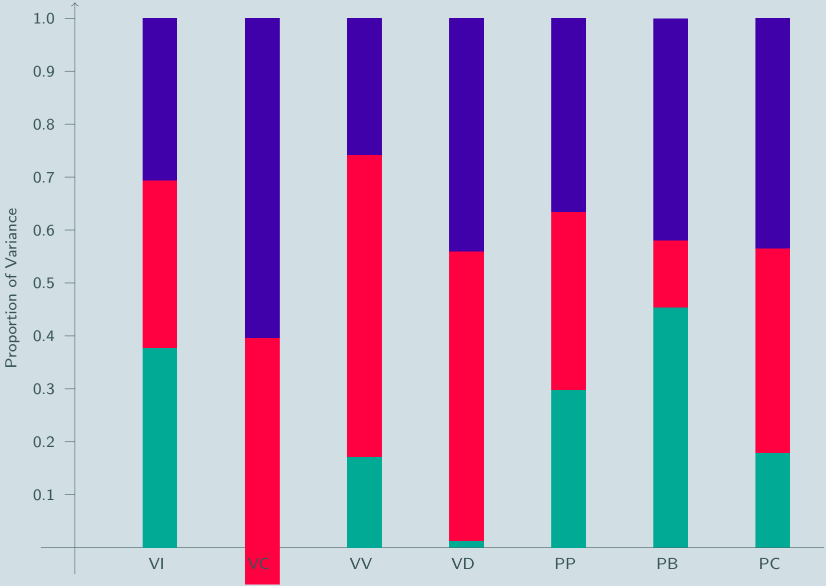
Missing data

- Out of c. 1200 twins only c. 500 have all variables of interest presentation
- Used multiple imputation to handle the missingness
- Imputation model currently quite preliminary:
  - all WISC subscales
  - SES measures from birth and age 7
  - age and sex
- Future work will add variables to improve tenability of MAR assumption; and impute zygosity

All variables have been standardised

Results: basic model

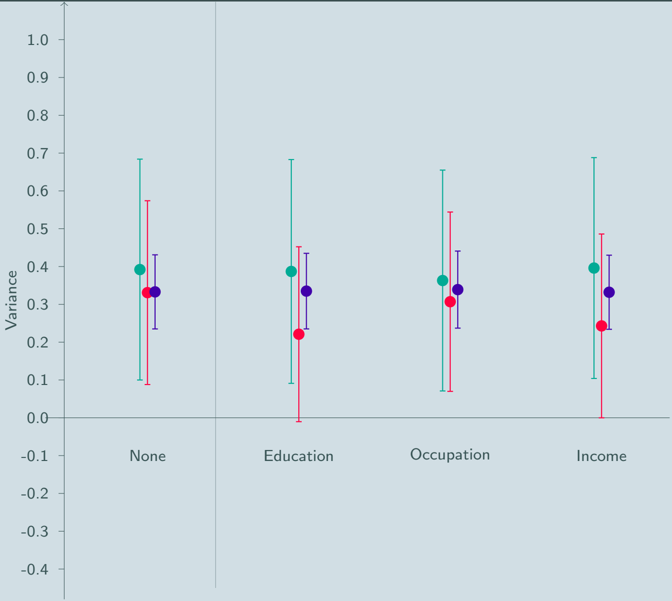
As proportions



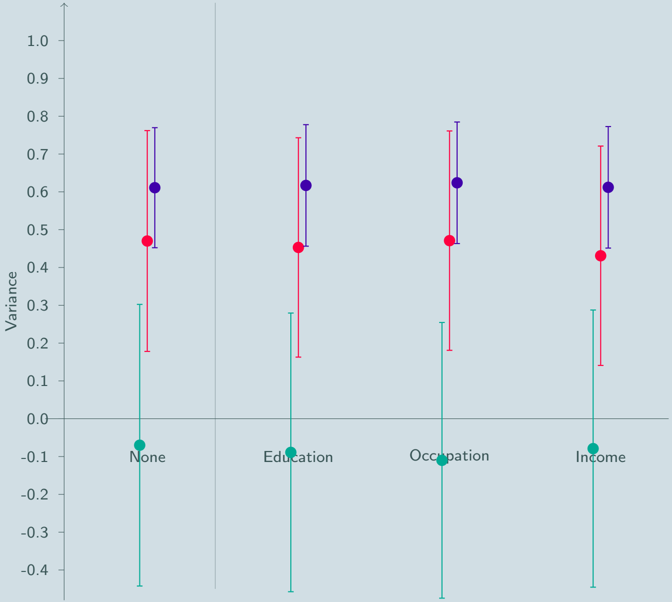
Adding explanatory variables

- Can some of the socioeconomic variables explain some of the shared environmental variation?
- Can they ‘explain’ some of the genetic variation (through genetic correlation)?

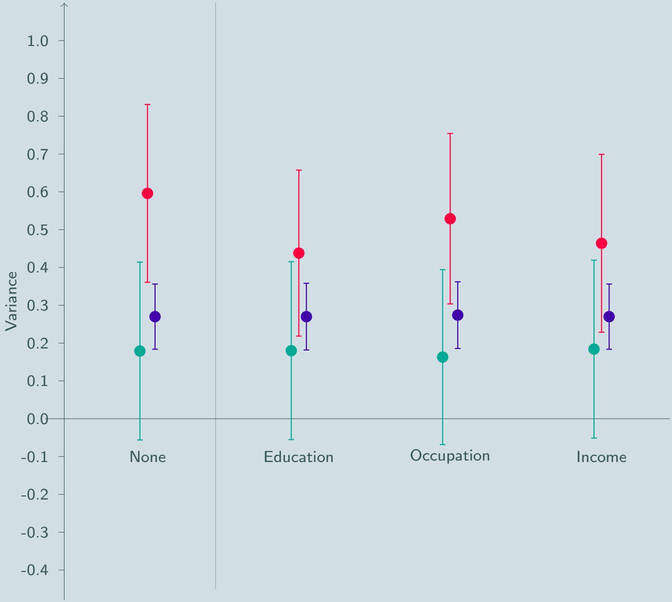
Information



Comprehension



Vocabulary



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Variance
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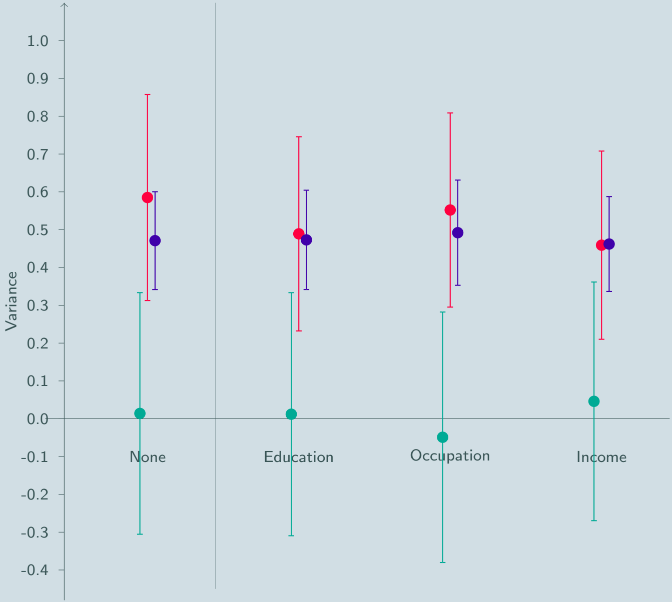
Education
Occupation
Income

Digit Span



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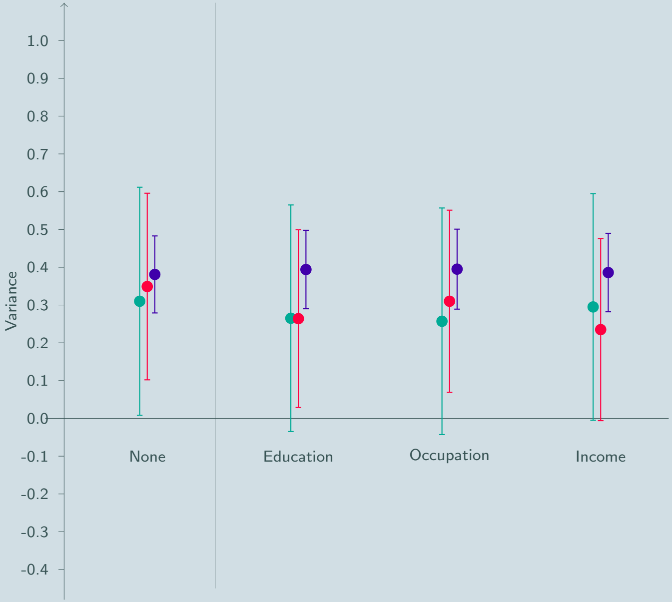
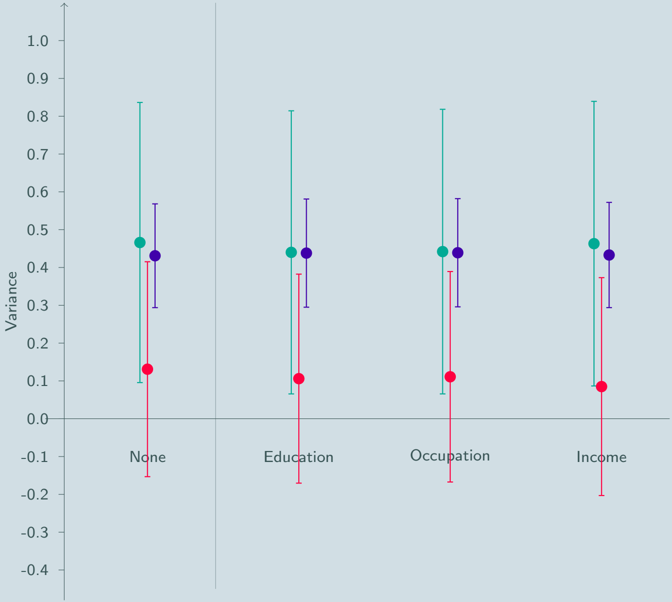


Block Design



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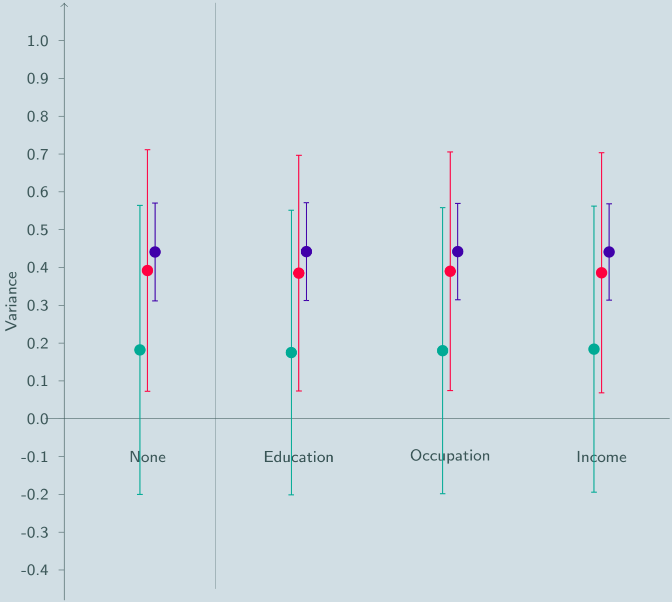
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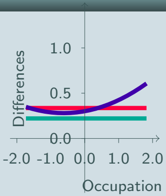
Results: differential model

Education



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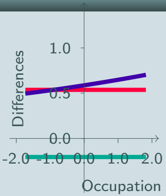

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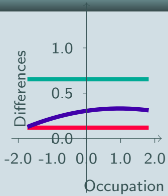

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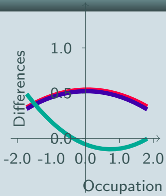

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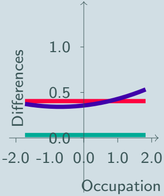

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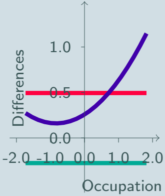

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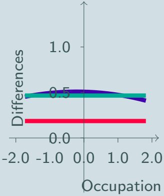
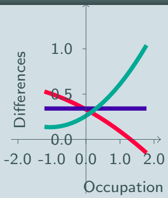


Coding

Occupation



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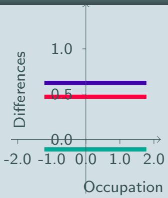

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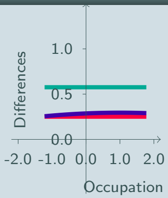

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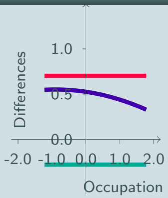

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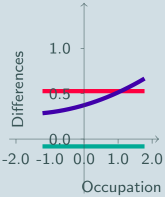

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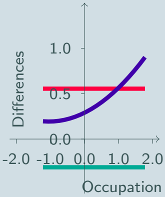

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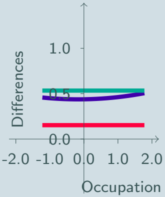

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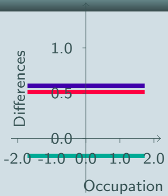
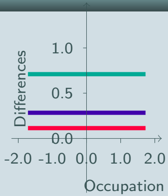
Income

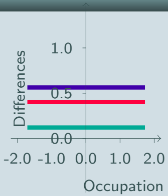
Information



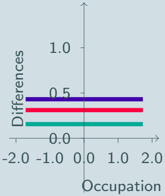
Comprehension



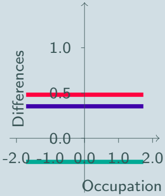
Vocabulary



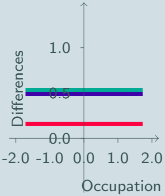
Digit Span



Picture Arrangement



Block Design



Coding

References

Bronfenbrenner, U. & Ceci, S. (1994) Nature-nurture reconceptualized in developmental perspective - a bioecological model *Psychological Review* **101(4)** pp568-586

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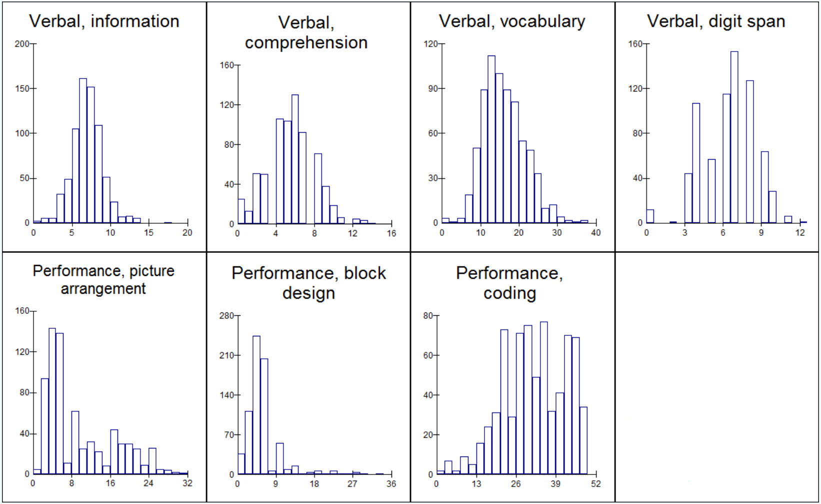
Tulsky, D. S., Saklofske, D. H., Chelune, G. J., Heaton, R. K., Ivnik, R. J., Bornstein, R., Prifitera, A. & Ledbetter, M. F. (2003) *Clinical interpretation of the WAIS-III and WMS-III*. Academic Press

Extras

- Distributions of variables
- Missing data patterns
- Other options: DeFries-Fulker regression
- Other options: structural equation modelling
- Details of the multilevel model

Distribution of the 7 scales



Some of these are clearly not very Normal.


Verbal info
Verbal comp
Verbal vocab
Verbal digit
Perf pic
Perf block
Perf coding
Education01
Occupation01
Income01
Education02
Occupation02
Income02
Education7
Occupation7
Income7
Number
6
186
58
16
4
44
22
10
8
4
2
2
2
2
2
1
11
1
1
5
27
9
1
1
1
5
1
1
575

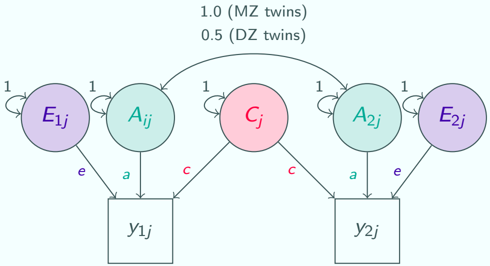
Fitting the model - option 1

$$\mathbf{score}_{1j} = \beta_0 + \beta_1 \mathbf{score}_{2j} + \beta_2 \mathbf{r}_j + \beta_3 \mathbf{r.score}_{2j} + e_j$$

DeFries-Fulker regression

- Fits a single level regression
- One twin's outcome is the response and the other twin's outcome an explanatory variable in various interactions
- Proportions of genetic and shared environmental variance given by β_3 and β_1 respectively
- Useful for restricting to range of outcome values of interest but not very extensible.

Fitting the model - option 2



Structural equation modelling

- Genetic, shared environmental, and non-shared environmental factors are latent variables with variances constrained to 1
- Components given by squares of respective loadings
- Twins' outcomes in separate variables
- Correlation between genetic latent variables constrained to be 1 for MZ and 0.5 for DZ twins

Fitting the model - option 3

Multilevel genetic model

- Two level model but with 3 (sets of) random effects
- Need reparameterisation to get software to fit it
- Rabe-Hesketh et al. (2008) provide two
  - fit a two level model with genetic effect for DZ twins split into shared (level 2) and non-shared (level 1) part, with variances constrained to be equal
  - or a three level model (level 1 = individual, level 3 = family, level 2 = individual (DZ) or family (MZ)) then desired components given by linear combinations of estimated variances

We use a multilevel genetic model with the first reparameterisation

Fitting the model - model used

First reparameterisation

$$y_{ij} = \beta_0 + u_j + g_{1j}\left(\mathbf{MZ}_j + \sqrt{0.5}\mathbf{DZ}_j\right) + g_{2ij}\left(\sqrt{0.5}\mathbf{DZ}_j\right) + e_{ij}$$

$$u_j \sim \mathrm{N}(0, \sigma^2_C)$$
$$g_{1j} \sim \mathrm{N}(0, \sigma^2_A)$$
$$g_{2ij} \sim \mathrm{N}(0, \sigma^2_A)$$
$$e_{ij} \sim \mathrm{N}(0, \sigma^2_E)$$

Second reparameterisation

Model

$$y_{ijk} = \beta_0 + u_k + g_{jk} + e_{ijk}$$

$$u_k \sim \mathrm{N}(0, \sigma_u^2)$$
$$g_{jk} \sim \mathrm{N}(0, \sigma_g^2)$$
$$e_{ijk} \sim \mathrm{N}(0, \sigma_e^2)$$

$$\sigma_C^2 = \sigma_u^2 - \sigma_g^2$$
$$\sigma_A^2 = 2\sigma_g^2$$
$$\sigma_E^2 = \sigma_e^2$$