Kognitionspsychologie II: Session 3

Intelligence: Nature & Nurture

Rui Mata, FS 2023

Version: March 21, 2023

Previous session…

The Psychometric Approach to Intelligence

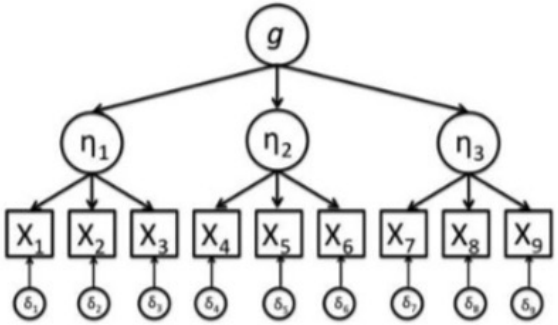


Figure 4. A hierarchical model of cognitive abilities.

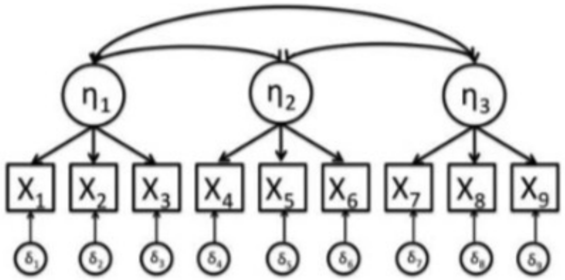


Figure 5. An oblique model of cognitive abilities.

although these models seem structurally different their fits (and predictions) are equivalent, making it difficult to obtain a definitive answer to the structure of mental functions!

Kovacs, K., & Conway, A. R. A. (2016). Process Overlap Theory: A Unified Account of the General Factor of Intelligence. ***Psychological Inquiry, 27***(3), 151–177. http://doi.org/10.1080/1047840X.2016.1153946

Markon, K. E. (2019). Bifactor and Hierarchical Models: Specification, Inference, and Interpretation. ***Annual Review of Clinical Psychology, 15***(1), 51–69. http://doi.org/10.1146/annurev-clinpsy-050718-095522

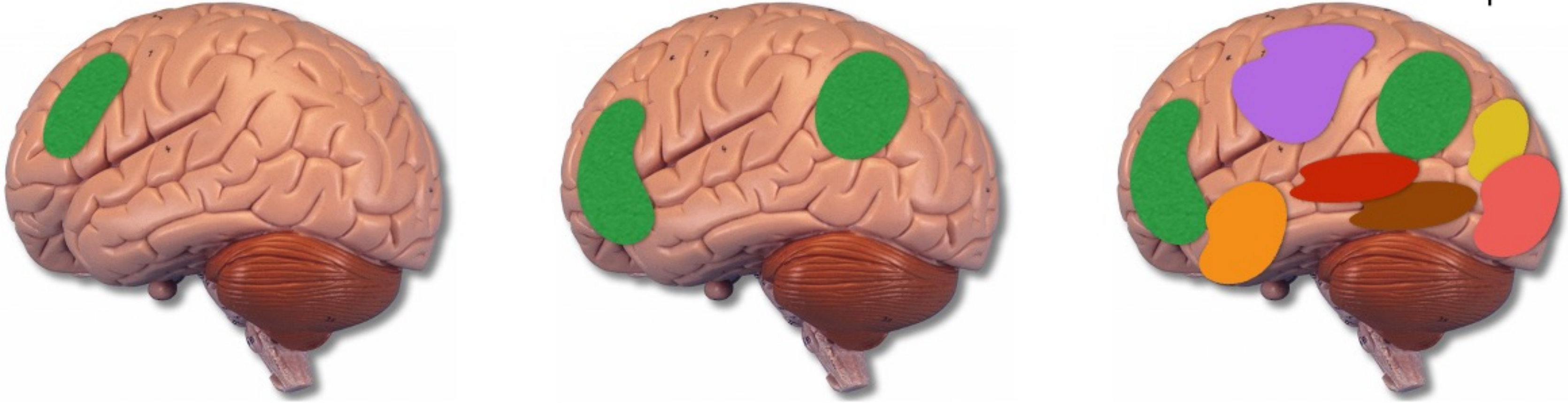
Previous session…

Neural Theories of Intelligence

Table I. Summary of Cognitive Neuroscience Theories of Human Intelligence

	Functional localization			System-wide topology and dynamics		
	Primary region	Primary network	Multiple networks	Small-world topology	Network flexibility	Network dynamics
Lateral PFC Theory [103]	✓	x	x	x	x	x
P-FIT Theory [75]	x	✓	x	x	x	x
MD Theory [82]	x	✓	x	x	x	x
Process Overlap Theory [83]	x	x	✓	x	x	x
Network Neuroscience Theory	x	x	✓	✓	✓	✓

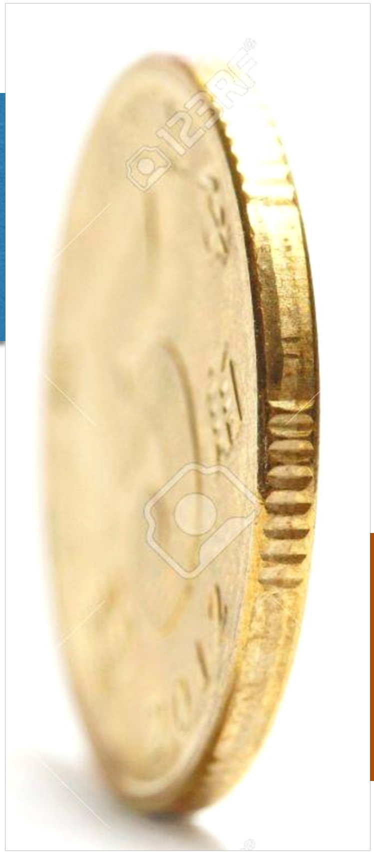
Lateral PFC P-FIT/MD Process Overlap



Network Neuroscience theory (NNT), like process overlap theory, assumes there are multiple networks relevant to intelligence but NNT emphasises system-wide topology (structure) and dynamics (function) that ensure the capacity to flexibly transition between network states

Barbey, A. K. (2018). Network Neuroscience Theory of Human Intelligence. ***Trends in Cognitive Sciences***, ***22***(1), 8–20. http://doi.org/10.1016/j.tics.2017.10.001

Part 1:
Heritability



Part 2:
Environmentality

Learning Objectives
Part 1: Heritability of intelligence

- Understand the concept of heritability and the logic of using familial studies (e.g., twin studies) to assess the genetic basis of individual differences in intelligence

- Be aware of genome wide association studies and polygenic scores as newer tools to assess the genetic basis of individual differences in intelligence

- Place the heritability of intelligence in relation to that of other human traits

- Be aware that heritability is a proportion and, therefore, can vary as a function of environmental circumstances

Behavioral Genetics

the field of study that examines the role of genetic and environmental influences on behaviour, such as the nature and origins of individual differences in behavior

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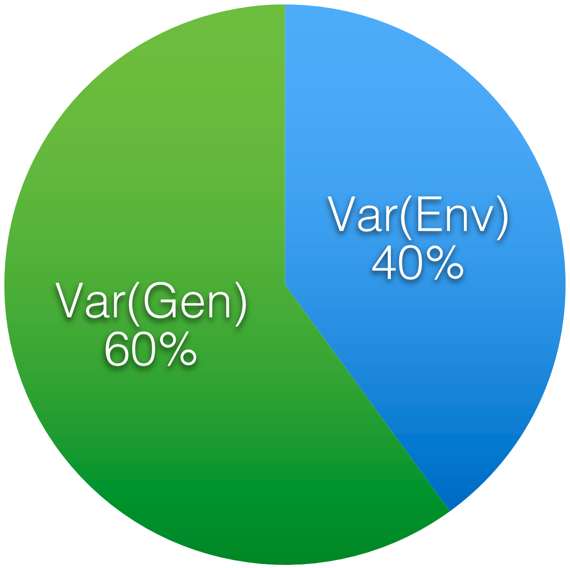
Heritability

Heritability (*H^2*) is a statistic used in genetics that estimates how much variation in a phenotypic trait in a population is due to genetic variation among individuals in that population.

Heritability is a proportion and, thus, varies between 0 and 1 (or 0 to 100%).

Var(*Phenotype*) = Var(*Gen*) + Var(*Env*)

Var(*Phenotype*)



NOTE: Heritability is *NOT* an estimate of whether a trait is determined by genes. That is, saying that a trait has a heritability estimate of 0.60 does not mean that the trait in one person is 60% caused by genes; it means that 60% of the **variability in the trait in a population (i.e., the differences between individuals)** is due to the variance of genetic factors among that population.

Moore, D. S., & Shenk, D. (2017). The heritability fallacy. ***Wiley Interdisciplinary Reviews: Cognitive Science***, ***8***(1-2), e1400. http://doi.org/10.1002/wcs.1400

Heritability

NOTE: finding that the heritability of a characteristic is high (e.g., 100%) does not necessarily mean that environmental factors cannot powerfully influence the development of that characteristic - it depends on how much variation there is in environmental conditions

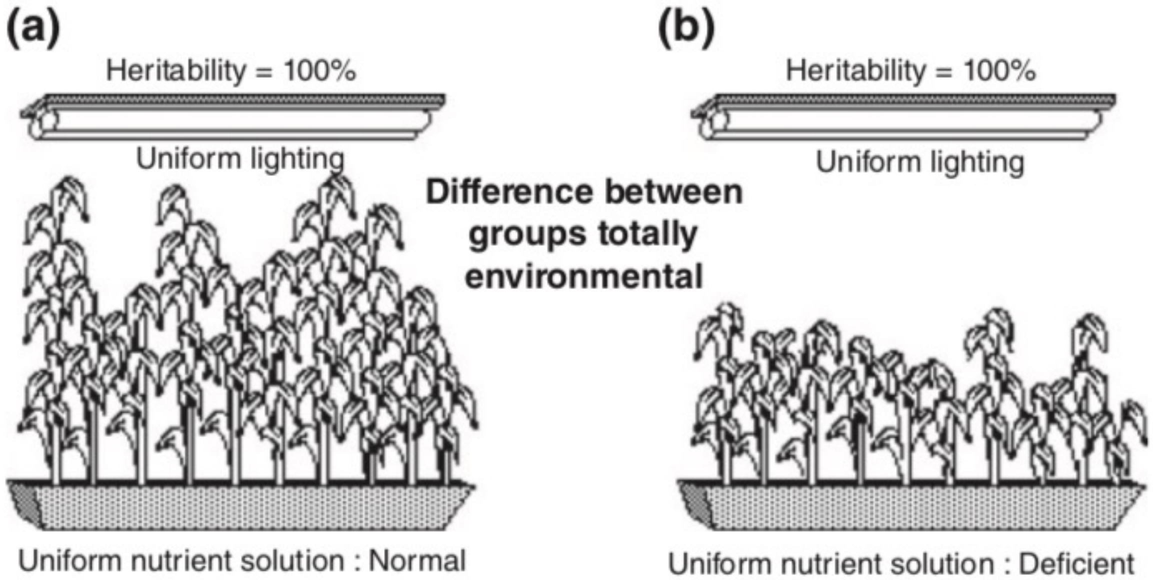
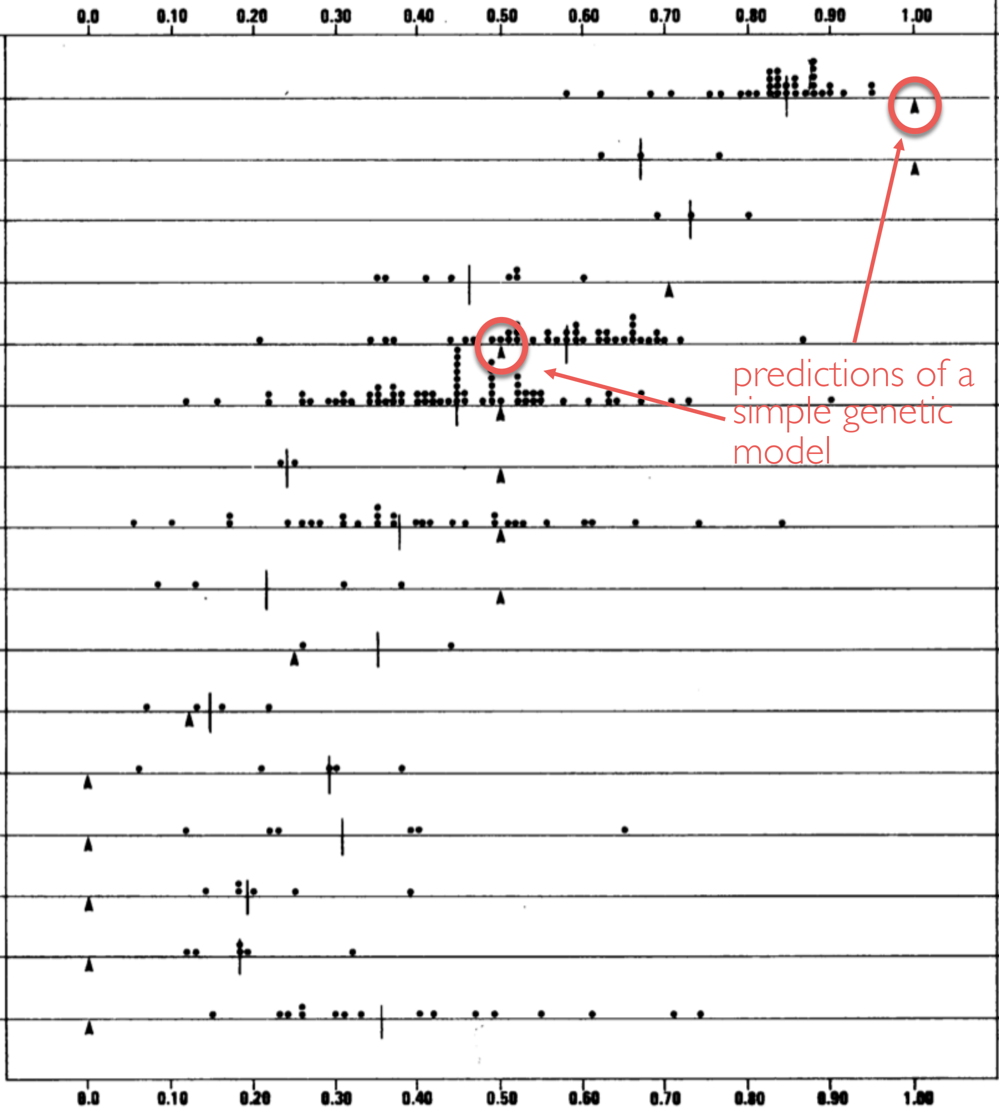


FIGURE 2 | Lewontin's thought experiment. Genetically variable seeds that develop in controlled environments grow to varying heights. The heritability of height in both the (a) and (b) panels is 100%, because all plants in each panel are exposed to the same environment; thus, all of the variation in height (within a panel) is accounted for by *genetic* variation. Despite height being 100% heritable in both the left panel *and* the right panel, plants' heights are still influenced by the quality of the nutrients they encounter in their environments; mature plants that develop in a deficient nutrient solution (b) are shorter, on average, than are mature plants that develop in a normal nutrient solution (a). Source: http://www.nyu.edu/gsas/dept/philo/faculty/block/papers/plants.gif) and Lewontin.[9]

Moore, D. S., & Shenk, D. (2017). The heritability fallacy. ***Wiley Interdisciplinary Reviews: Cognitive Science***, ***8***(1-2), e1400. http://doi.org/10.1002/wcs.1400

Familial Studies of Intelligence

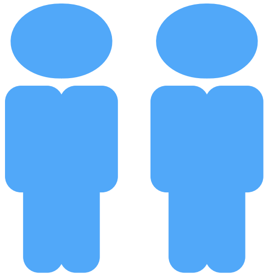


	NO. OF CORREL-ATIONS	NO. OF PAIRINGS	MEDIAN CORREL-ATION	WEIGHT-ED AVER-AGE	χ^2 (d.f.)	$\chi^2 \div$ d.f.
MONOZYGOTIC TWINS REARED TOGETHER	34	4672	.85	.86	81.29 (33)	2.46
MONOZYGOTIC TWINS REARED APART	3	65	.67	.72	0.92 (2)	0.46
MIDPARENT–MIDOFFSPRING REARED TOGETHER	3	410	.73	.72	2.66 (2)	1.33
MIDPARENT–OFFSPRING REARED TOGETHER	8	992	.475	.50	8.11 (7)	1.16
DIZYGOTIC TWINS REARED TOGETHER	41	5546	.58	.60	94.5 (40)	2.36
SIBLINGS REARED TOGETHER	69	26,473	.45	.47	403.6 (64)	6.31
SIBLINGS REARED APART	2	203	.24	.24	.02 (1)	.02
SINGLE PARENT–OFFSPRING REARED TOGETHER	32	8433	.385	.42	211.0 (31)	6.81
SINGLE PARENT–OFFSPRING REARED APART	4	814	.22	.22	9.61 (3)	3.20
HALF-SIBLINGS	2	200	.35	.31	1.55 (1)	1.55
COUSINS	4	1,176	.145	.15	1.02 (2)	0.51
NON-BIOLOGICAL SIBLING PAIRS (ADOPTED/NATURAL PAIRINGS)	5	345	.29	.29	1.93 (4)	0.48
NON-BIOLOGICAL SIBLING PAIRS (ADOPTED/ADOPTED PAIRINGS)	6	369	.31	.34	10.5 (5)	2.10
ADOPTING MIDPARENT–OFFSPRING	6	758	.19	.24	6.8 (5)	1.36
ADOPTING PARENT–OFFSPRING	6	1397	.18	.19	6.64 (5)	1.33
ASSORTATIVE MATING	16	3817	.365	.33	96.1 (15)	6.41

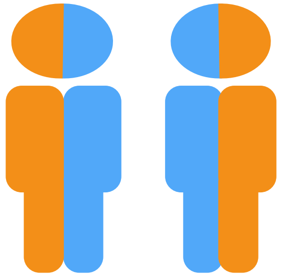
Bouchard, T. J., & McGue, M. (1981). Familial studies of intelligence: A review. ***Science, 212***(4498), 1055–1059.

Estimating heritability from familial studies

$r_{MZ} = .86$



$r_{DZ} = .60$



MZ: ***monozygotic*** ("identical"), meaning that MZ twins can develop from just one zygote that will then split and form two embryos with identical genetic material (**100%** shared genetic material)

DZ: ***dizygotic*** ("fraternal"), meaning that they can develop from two different eggs; each are fertilized by separate sperm cells that only share half of their genetic material like any siblings (**50%** shared genetic material).

$$\mathrm{Var}(\mathit{Phenotype}) = \mathrm{Var}(\mathit{Gen}) + \mathrm{Var}(\mathit{Env})$$

	A (additive genetics)	C (common environment) +	E (unique environment)
MZs	share **100% A**	share **100% C**	share **0% E**
DZs	share **50% A**	share **100% C**	share **0% E**

Estimating heritability from familial studies

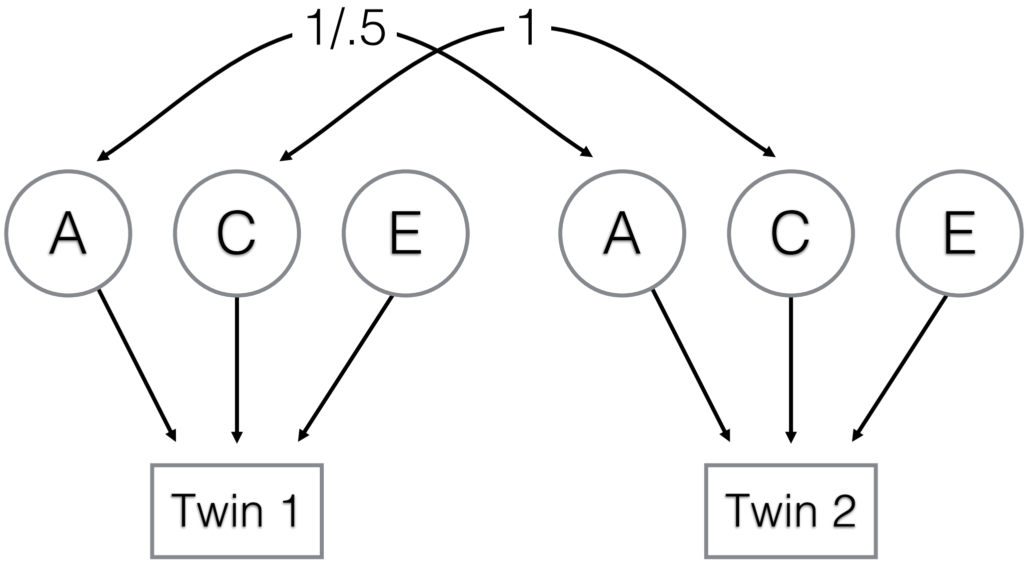
Familial studies use a subtraction logic…

Formula	explanation
$A = 2 (r_{MZ} - r_{DZ})$ Falconer's formula	MZs and DZs differ by half a genome, consequently the difference in the similarities between MZs (quantified by r_{mz}) and DZs (quantified by r_{dz}) that is determined by genetics is half a genome. In numbers: half of a genome explains ½ A = .86 - .60 = .26 of the variance, and, therefore, a whole genome explains, A = 2 × .26 = **.52** of the variance.
$C = r_{mz} - A$	MZs similarities (quantified by r_{mz}) are due to both 100% shared genetic material and their shared common environment, consequently, subtracting the similarity due to genetics (A) leads to an estimate of the similarity due to the common environment. In numbers, C = .86 - .52 = **.34**
$E = 1 - r_{mz}$	The unique environment (E) is responsible for the observed differences between MZs because they share 100% of genetics and common upbringing. In numbers, E = 1 - .86 = **.14**

Note that the numbers in **bold** are a ballpark estimate based on part of the data of Bouchard and McGue (1981). More recent meta-analytic results and slightly different methods, produce quite similar but somewhat different estimates (cf. Polderman et al., 2015).

Modern Modeling of Genetic and Environment Effects

The formulas presented in the previous slide are not adequate for testing equivalence between multiple groups (sex differences, multiple studies) and has been replaced by more advanced methods (see example model below). The logic of capitalising on shared and unique factors between different groups (for example, DZ and MZ), however, remains the same!



The figure depicts a structural equation model for the basic twin ACE model. The additive (A) factor is correlated 1 between MZ twins and 0.5 between DZ twins.. Shared family environment (C) is correlated 1 for both MZ and DZ twins that are reared together. Unique environment (E) is the source of variance that will result in differences among members of one family and is, thus, uncorrelated between members of MZ and DZ pairs. This is one of the simplest models that can be estimated (cf. Rijsdijk & Sham, 2002, for others).

Rijsdijk, F. V., & Sham, P. C. (2002). Analytic approaches to twin data using structural equation models. ***Briefings in Bioinformatics, 3***(2), 119–133.

New methods in behavioral genetics: polygenic scores

New methods rely on genotyping many individuals and assessing directly the links between single base pair differences in inherited DNA (Single Nucleotide Polymorphisms, SNPs) and the phenotype of interest. The effect size of each SNP association is very small but aggregating thousands of these minuscule effects in a genome - wide polygenic score (GPS) can explain considerable portions of variance (currently ca. 10% for intelligence; and virtually all variance in height, cf. https://www.nature.com/articles/d41586-022-03029-4). This implies that behavioural genetics is not restricted to familial studies and SNPs can be used to calculate heritability.

SNP	Increasing allele	Allele 1	Allele 2	Genotypic score	Correlation with trait	Weighted genotypic score
SNP 1	T	A	T	1	0.005	0.005
SNP 2	C	G	G	0	0.004	0.000
SNP 3	A	A	A	2	0.003	0.006
SNP 4	G	C	G	1	0.003	0.003
SNP 5	G	C	C	0	0.003	0.000
SNP 6	T	A	T	1	0.002	0.002
SNP 7	C	C	G	1	0.002	0.002
SNP 8	A	A	A	2	0.002	0.004
SNP 9	A	T	T	0	0.001	0.000
SNP 10	C	C	G	1	0.001	0.001
Polygenic score				**9**		**0.023**

Plomin, R., & Stumm, von, S. (2018). The new genetics of intelligence. ***Nature Reviews Neuroscience***, 1–12. http://doi.org/10.1038/nrg.2017.104

Heritability of intelligence and other traits

‘first law of behavioural genetics’: everything is heritable

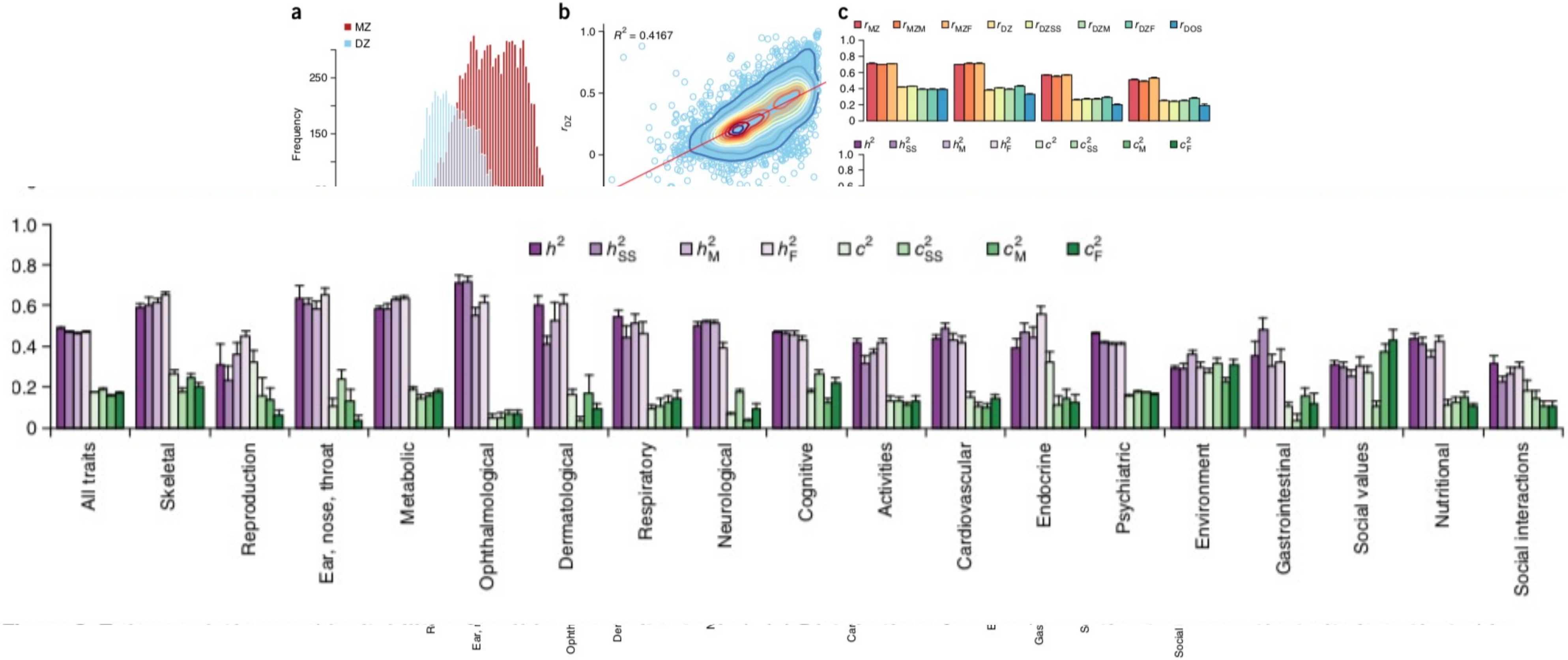


Figure 2 Twin correlations and heritabilities for all human traits studied. (**a**) Distribution of r_{MZ} and r_{DZ} estimates across the traits investigated in 2,748 twin studies published between 1958 and 2012. r_{MZ} estimates are based on 9,568 traits and 2,563,628 partly dependent twin pairs; r_{DZ} estimates are based on 5,220 traits and 2,606,252 partly dependent twin pairs (**Table 1**). (**b**) Relationship between r_{MZ} and r_{DZ}, using all 5,185 traits for which both were reported. (**c**) Random-effects meta-analytic estimates of twin correlations (top) and reported variance components (bottom) across all traits separately for four age cohorts. Error bars, standard errors. (**d**) Random-effects meta-analytic estimates of twin correlations (top) and reported variance components (bottom) across all traits, and within functional domains for which data on all correlations and variance components were available. Error bars, standard errors.

The largest meta-analysis of heritability of human traits to date:

Polderman, T. J. C., Benyamin, B., de Leeuw, C. A., Sullivan, P. F., van Bochoven, A., Visscher, P. M., & Posthuma, D. (2015). Meta-analysis of the heritability of human traits based on fifty years of twin studies. ***Nature Genetics***, ***47***(7), 702–709.

Interim summary
Part 1: Heritability of Intelligence

- **Behavioural genetics:** the field of study that examines the role of genetic and environmental influences on behaviour
- **Heritability:** statistic used in (behavioral) genetics that quantifies how much variation in a phenotype in a population is due to genetic variation among individuals in that population; varies between 0 and 1 (or 0 to 100%); a relative measure that may vary as a function of variation in environmental exposure – this value says nothing about the mechanisms of intelligence in single individuals…
- **Familial studies:** familial studies explore assumptions about genetic (% shared genome) and environmental similarities (shared wombs & homes) of family members to obtain estimates of heritability; twin studies have been the workhorse of behavioural genetics but more recently studies that make use of genotyping have become alternative methods that do not require family relations to estimate heritability
- **Heritability of intelligence:** current studies suggest a large genetic component of individual differences in intelligence (ca. .6; but see next section)

Learning Objectives
Part 2: Environmentality of Intelligence

- Learn about evidence that intelligence is malleable and can be improved by specific interventions (e.g., education)

- Learn about the secular increases in intelligence - Flynn effect

- Understand that heritability is specific to a particular population and time…

- Learn about transactional models

- So, what is ***g***?

Environmentality

Education has effects on intelligence

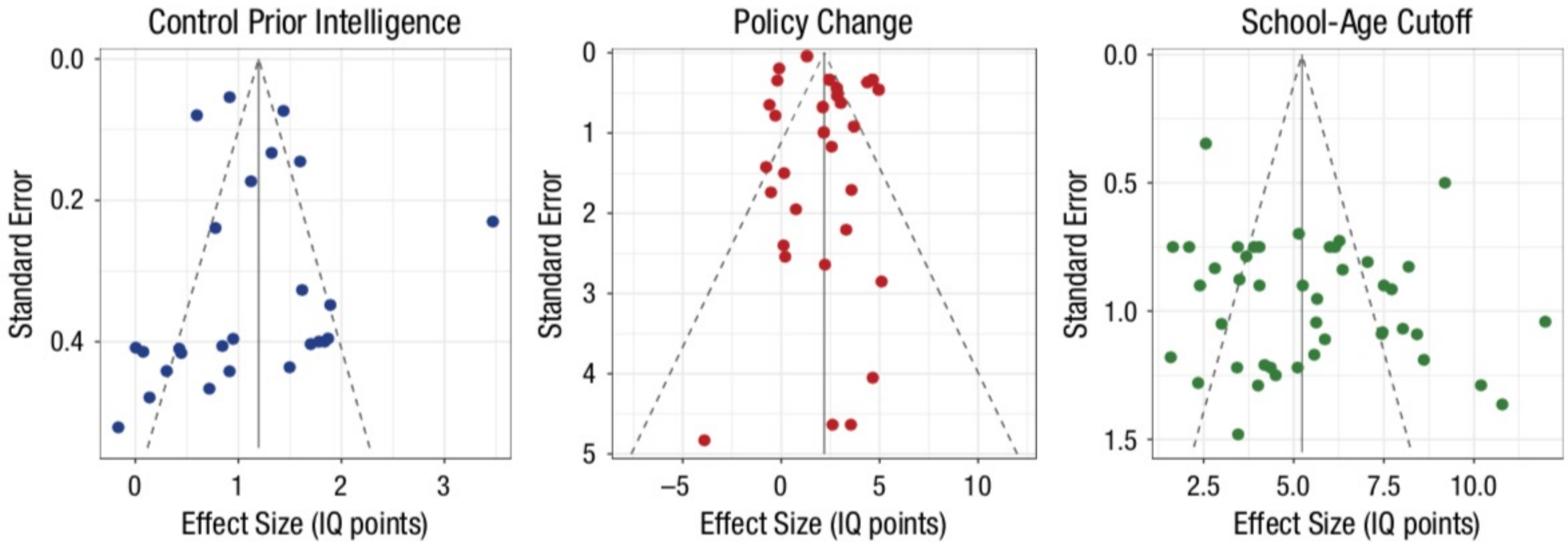


Fig. 2. Funnel plots showing standard error as a function of effect size, separately for each of the three study designs. The dotted lines form a triangular region (with a central vertical line showing the mean effect size) where 95% of estimates should lie in the case of zero within-group heterogeneity in population effect sizes. Note that 42 of the total 86 standard errors reported as approximate or as averages in the original studies were not included for the school-age-cutoff design.

control prior intelligence = longitudinal studies in which cognitive testing data were collected before and after variation in the duration of education (e.g., before and after university vs. no university)

policy change = study of the effects of a change in educational duration (e.g., increase of compulsory education by 1 year) on mental testing

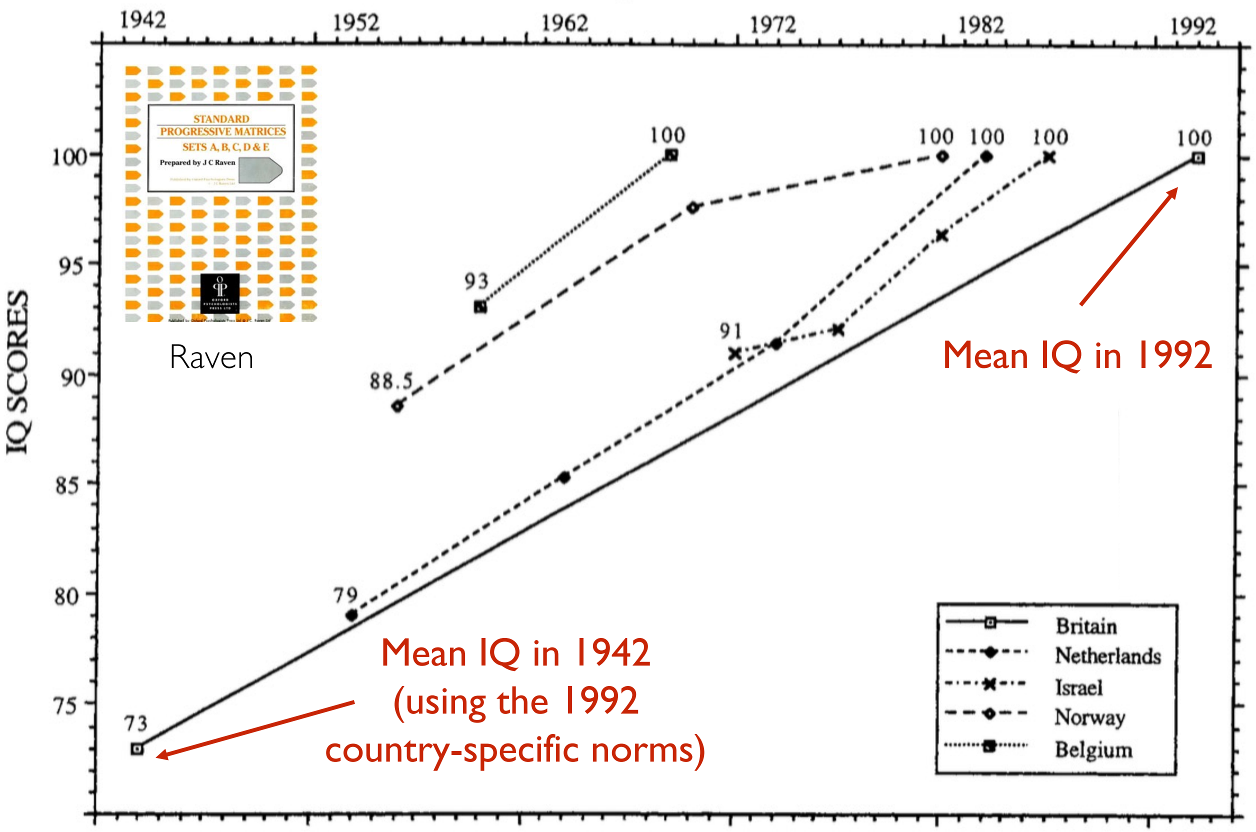
school-age cutoff = studies use regression-discontinuity analysis to leverage the fact that school districts implement a date-of-birth cutoff for school entry (example: compare 3.9-year olds that did not attend "Kindsgi" vs. 4.0 year-olds that did)

Ritchie, S. J., & Tucker-Drob, E. M. (2018). How much does education improve intelligence? A meta-analysis. *Psychological Science*, *29*(8), 1358–1369. http://doi.org/10.1177/0956797618774253

Environmentality

Intelligence can change across cohorts (Flynn effect)

The Flynn effect is the substantial and long-sustained increase in both fluid and crystallized intelligence test scores measured in many parts of the world from roughly 1940s to the present day. When IQ tests are initially standardized using a sample of test-takers, by convention the average of the test results is set to 100 and their standard deviation is set to 15. When IQ tests are revised, they are again standardized using a new sample of test-takers, usually born more recently than the first. Again, the average result is set to 100. However, when the new test subjects take the older tests, their average scores are typically above 100.



Flynn, J. R. (1999). Searching for justice: The discovery of IQ gains over time. ***American Psychologist***, 54, 5-20.

The most comprehensive meta-analysis of the Flynn effect to date (k = 285, *N* = 14,031), suggest an average effect of ca. 2 IQ points per decade:
Trahan, L. H., Stuebing, K. K., Fletcher, J. M., & Hiscock, M. (2014). The Flynn effect: A meta-analysis. ***Psychological Bulletin, 140***(5), 1332–1360. doi:10.1037/a0037173

Environmentality

Intelligence can change across cohorts (Flynn effect)

“It seems likely that the ultimate cause of IQ gains is the Industrial Revolution, which produced a need for increased intellectual skills that modern societies somehow rose to meet. The intermediate causes of IQ gains may include such factors as a more favorable ratio of adults to children, better schooling, more cognitively demanding jobs, and more cognitively challenging leisure. Flynn (2009) has argued that one proximate cause is the adoption of a scientific approach to reasoning with an attendant emphasis on classification and logical analysis.”

Nisbett, R.E., Aronson, J. & Blair, C., Dickens, W., Flynn, J., Halpern, D.F. & Turkheimer, E. (2012). Intelligence: New findings and theoretical developments. ***American Psychologist, 67***, 130-159.

Environmentality

Heritability is not constant across cohorts!

Table 2. Selected Studies Suggesting Changing Heritability of Behavioral Traits in Different Environments

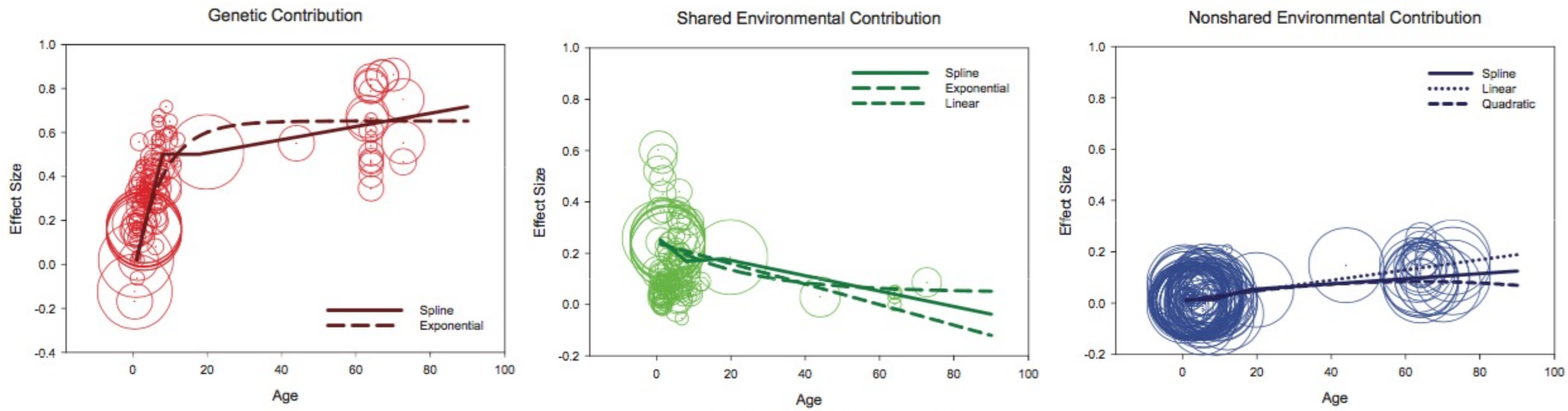
Source, y	Measure	Sample	Environmental Variable	Results
Heath et al,[31] 1985	Years of education	Male twins from Norwegian Twin Registry	Pre– vs post–World War II historical cohort	Higher heritability in more recent cohorts where school advancement more merit based
Heath et al,[32] 1989	Alcohol consumption	Twins from Australian Registry	Martial status	Greater heritability in single vs married individuals
Fishbein et al,[33] 1990	Reading and math achievement	Swedish twin school children	Permissive vs restrictive class	Higher heritability in permissive vs restrictive class
Lichtenstein et al,[34] 1992	Educational achievement	Swedish twins raised together and apart	Historical cohort	Higher heritability in those <60 vs >60 years of age
Dunne et al,[35] 1997	Age at first intercourse	Australian Twin Registry	Historical cohort	Greater heritability in more recent cohorts
Rowe et al,[36] 1999	Aggression	US adolescent twins and siblings	Family warmth	Greater heritability in schools with higher mean family warmth
Boomsma et al,[37] 1999	Disinhibition	Dutch adolescent twins	Religious upbringing	Higher heritability in those with a nonreligious vs religious upbringing
Rowe et al,[36] 1999	Vocabulary IQ	US adolescent twins and siblings	Parental education	Greater heritability in more highly educated families
Kendler et al,[38] 2000	Regular tobacco use	Female-female Swedish twins reared together and apart	Historical cohort	Greater heritability in more recent cohorts with higher levels of tobacco use

Heritability estimates can vary across cohorts because environmental effects and variance in the trait differ or change across populations and historical periods. Many of the results above may be explained by the idea that higher heritability is found in environments that provide a greater diversity of exposures…

Kendler, K. S. (2001). Twin studies of psychiatric illness: An update. ***Archives of General Psychiatry, 58***(11), 1005–1014.

Environmentality

Heritability is not constant across the life span!



Tucker-Drop and Briley meta-analysed 15 longitudinal samples, involving monozygotic twin pairs raised together, dizygotic twin pairs raised together, monozygotic twin pairs raised apart, dizygotic twin pairs raised apart, adoptive sibling pairs, and nonadoptive sibling pairs, ranging in age from infancy through late adulthood.

"Cross-time correlations for genetic and shared environmental components were, respectively, low and moderate during early childhood, increased sharply over child development, and remained high from adolescence through late adulthood. Cross-time correlations for nonshared environmental components were low across childhood and gradually increased to moderate magnitudes in adulthood. "

Tucker-Drob, E. M., & Briley, D. A. (2014). Continuity of genetic and environmental influences on cognition across the life span: A meta-analysis of longitudinal twin and adoption studies. ***Psychological Bulletin, 140***(4), 949–979.

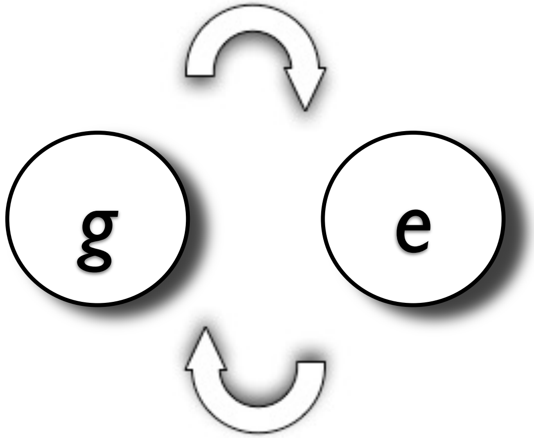
Paradox? Large heritability but considerable environmentality…

"Heritability is the proportion of variability in a phenotype that is "accounted for" (in the usual regression sense) by variation in genotype. Most studies estimate that the heritability of IQ is somewhere between .4 and .8 (and generally less for children), but it really makes no sense to talk about a single value for the heritability of intelligence. The heritability of a trait depends on the relative variances of the predictors, in this case genotype and environment. The concept of heritability has its origins in animal breeding, where variation in genotype and environment is under the control of the experimenter, and under these conditions the concept has some real-world applications. **In free-ranging humans, however, variability is uncontrolled, there is no "true" degree of variation to estimate, and heritability can take practically any value for any trait depending on the relative variability of genetic endowment and environment in the population being studied**. In any naturally occurring population, the heritability of intelligence is not zero (if genotype varies at all, it will be reflected in IQ scores) and it is not one (if environment varies at all, it will be reflected in IQ scores)."

Nisbett, R.E., Aronson, J. & Blair, C., Dickens, W., Flynn, J., Halpern, D.F. & Turkheimer, E. (2012). Intelligence: New findings and theoretical developments. ***American Psychologist, 67***, 130-159.

Paradox? Large heritability but considerable environmentality…

Transactional Models



Transactional models posit that these gene-environment correlations are key mechanisms of cognitive development. Early genetically influenced behaviors lead a person to select (and to be selected into) particular types of environments; these environments, in turn, have causal effects on cognition and serve to reinforce the original behaviors that led to those experiences.

Above-average abilities lead to selection of individuals into specific environments, thus masking environmental effects that are due to (potentially small) genetic effects. Crucially, a general intelligence factor can arise in such models because people who are better at any cognitive skill are more likely to end up in environments that cause them to develop all skills.

Tucker-Drob, E. M., Briley, D. A., & Harden, K. P. (2013). Genetic and environmental influences on cognition across development and context. ***Current Directions in Psychological Science, 22***(5), 349–355. doi:10.1177/0963721413485087

Dickens, W. T., & Flynn, J. R. (2001). Heritability estimates versus large environmental effects: The IQ paradox resolved. ***Psychological Review, 108***, 346-369.

Interim Summary
Part 2: Environmentality of intelligence

- **Environmentality:** a neologism to emphasise the malleable nature of psychological traits, such as intelligence; examples include effects of education on IQ, Flynn effect, heritability differences across cohorts and the life span

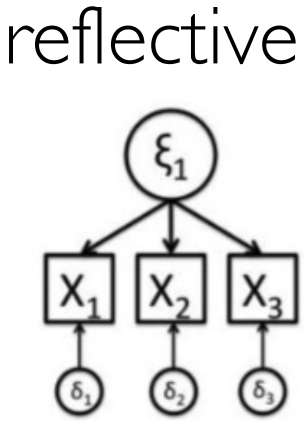
- **Flynn effect:** the finding of secular gains in IQ; demonstrated by newer cohorts performing better on the same test relative to past cohorts (ca. 2 IQ points per decade)

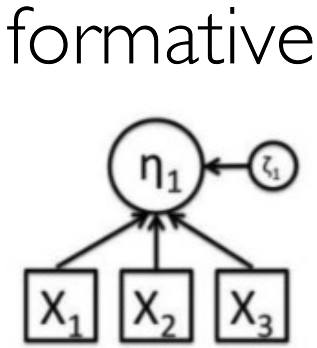
- **Heritability is not constant!** Heritability is not constant across cohorts or the life span; higher heritability is likely found in environments that provide a greater diversity of exposures

- **Transactional models:** emphasise the interaction between genetics and the environment; help explain why heritability can increase across the life span - small genetic effects have cumulative effects by leading individuals to select and being selected into specific environments

- ***g***: transactional models also suggest another reason for *g* - a general intelligence factor can arise because individuals with specific characteristics/skills are more likely to end up in environments that cause them to develop a large set of skills

What is g?





the two models are formally equivalent but conceptually distinct; **g** is a central psychological construct (and statistical device) developed to account for the empirical findings of a positive manifold; yet, it is still controversial whether to think of it as <u>cause</u> or <u>consequence</u> of how the mind works…

g as general capacity

- **g** captures a general capacity, mental energy, or brain process that is necessary for the functioning of other more specific abilities.

g as process overlap

- no measure captures a single capacity purely, correlations between measures arise from each tapping to some extent into similar abilities (and, potentially, some being more often needed than others).

g as a consequence of development

- g as the result of a transactional process: People with certain abilities tend to select and be selected into environments that will lead to development in several abilities.

Biology

The Genetic Lottery: *Why DNA Matters for Social Equality*

Kathryn Paige Harden

A provocative and timely case for how the science of genetics can help create a more just and equal society