Nature and nurture in education

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L'inné, l'acquis, pourquoi tant de controverses?

- Notions mal définies et incohérentes
- Notions mal interprétées par le grand public
- Les résultats scientifiques pertinents sont mal connus et mal compris
- Ils font l'objet d'exagérations considérables dans les médias
- On leur attribue des implications philosophiques voire politiques qu'ils n'ont pas.

Problèmes de la dichotomie inné/acquis

- Inné = présent à la naissance (congénital)
- Acquis = acquis par l'expérience.
- Mais à la naissance l'organisme a déjà été influencé par l'expérience.
- Bien après la naissance, l'organisme continue à se développer suivant un plan déterminé par les gènes.
- Cf. Mameli & Bateson (2006): 26 definitions of innateness, all problematic!

Génétique vs environnement
Une meilleure dichotomie, mais qui peut être trompeuse

- L'environnement est supposé contenir l'apprentissage et les facteurs psychologiques.
- Mais il inclus aussi des facteurs biologiques influençant le développement (ex: virus, toxines, nutrition).
- Dans tous les cas les facteurs environnementaux influencent l'organisme via des facteurs biologiques (notamment en modifiant des connexions synaptiques dans le cerveau, et/ou en altérant l'expression du génome).
- On peut distinguer les facteurs génétiques et non-génétiques mais en pratique les deux types de facteurs existent toujours et interagissent en permanence.
- La dichotomie n'en est pas une:
  SOIT génétique, SOIT environnemental

Individual differences in cognitive abilities

The case of IQ

Intellectual quotient: subtests (from Wechsler's batteries)

Verbal

- Vocabulary
- Similarities
- Comprehension
- Information
- Digit span
- Letter-number sequencing
- Arithmetic

Non verbal

- Block design
- Picture concepts
- Matrix reasoning
- Picture completion
- Coding
- Symbol search
- Cancellation

What cognitive abilities does IQ measure?

- Vocabulary
- Verbal abilities
- Verbal short-term and working memory
- Language-based reasoning (arithmetic)
- Speed of processing
- Visual-spatial skills
- Abstract reasoning
- Attention, concentration

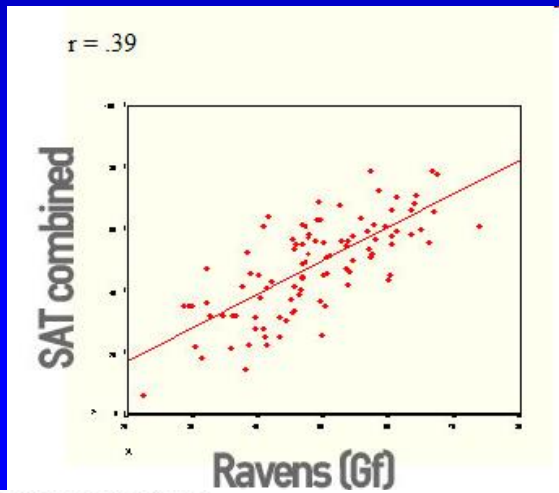
What aspects of human cognition does IQ **not** measure?

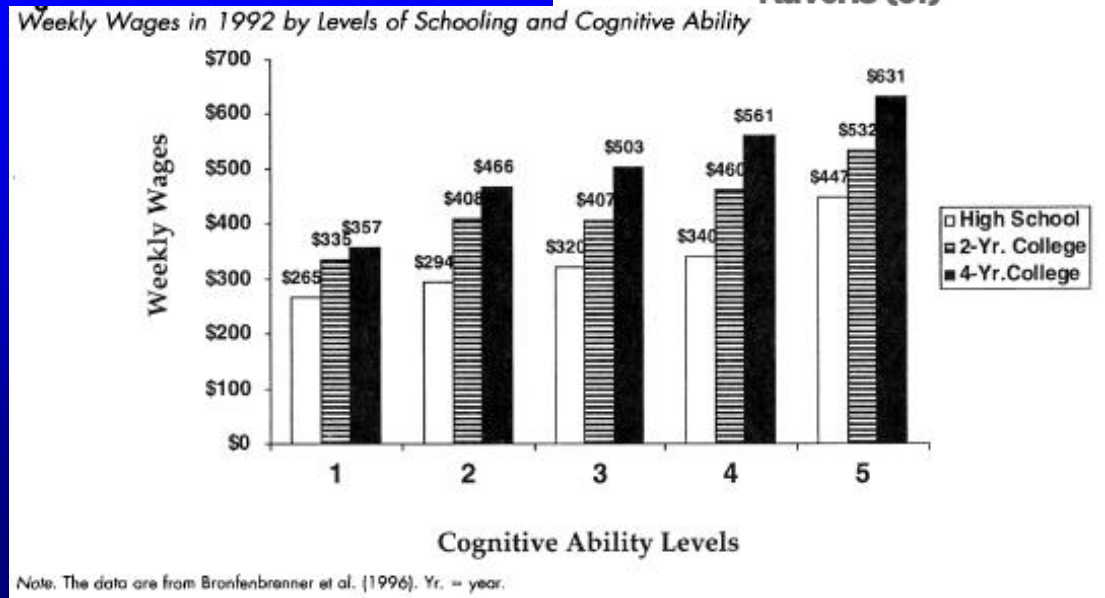
- Flexibility
- Planification (little)
- Numeric skills (little)
- Motor and sensorimotor skills (little)
- Social cognition, empathy
- Emotional regulation
- Creativity
- Humour
- Artistic skills
- Motivation
- Moral sense

What does IQ predict?

- Academic achievement (e.g., Rohde & Thompson 2007, Deary et al. 2007).
- Income (e.g., Ceci & Williams 1997)
- Health, longevity…

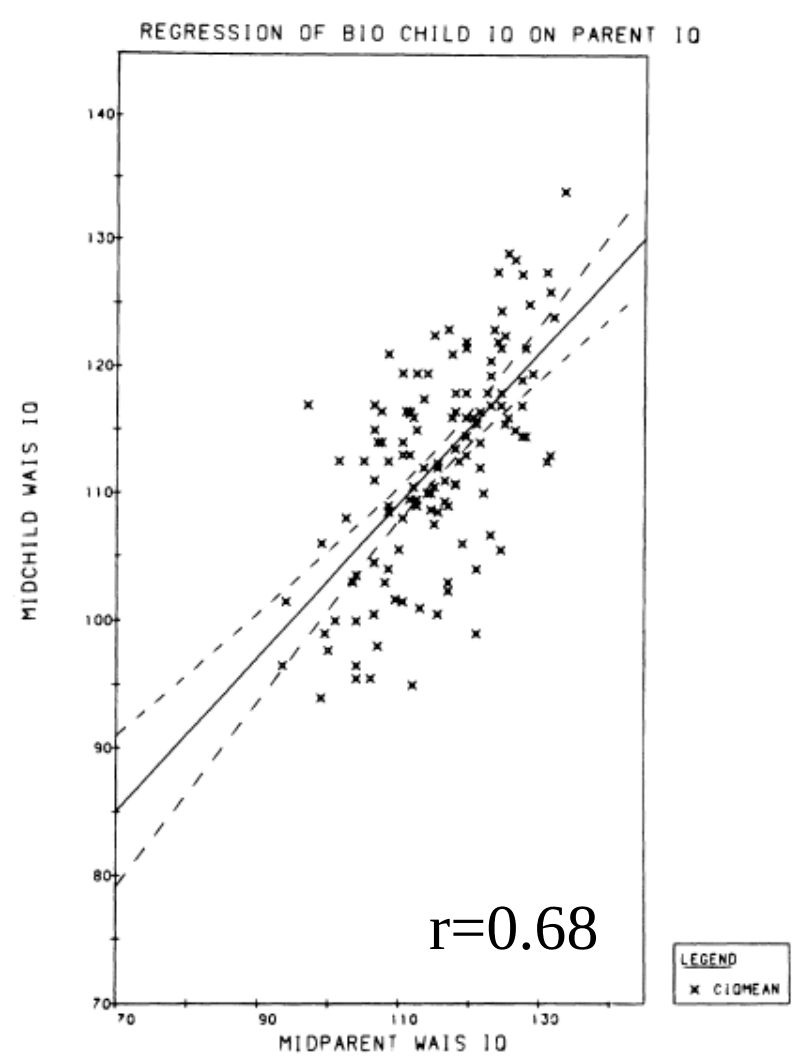
→ Despite its limitations, IQ provides an estimate of certain cognitive abilities that influence important aspects of an individual's life.

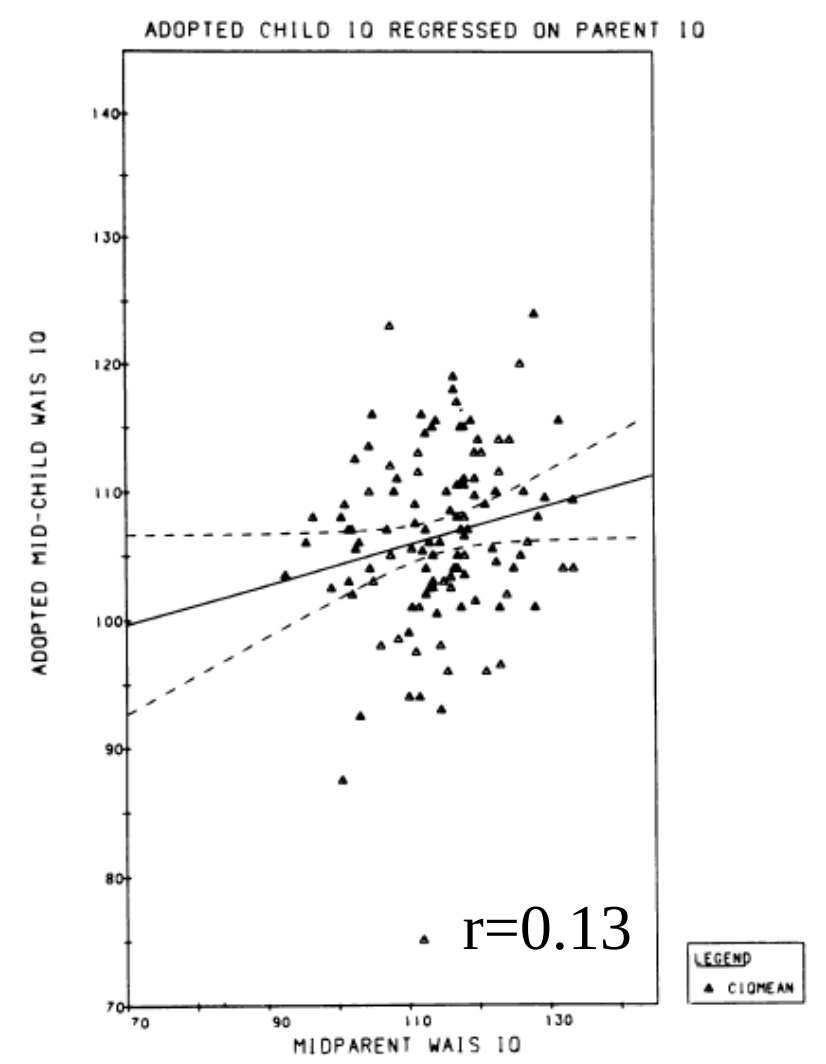




Corrélation du QI entre parents et enfants

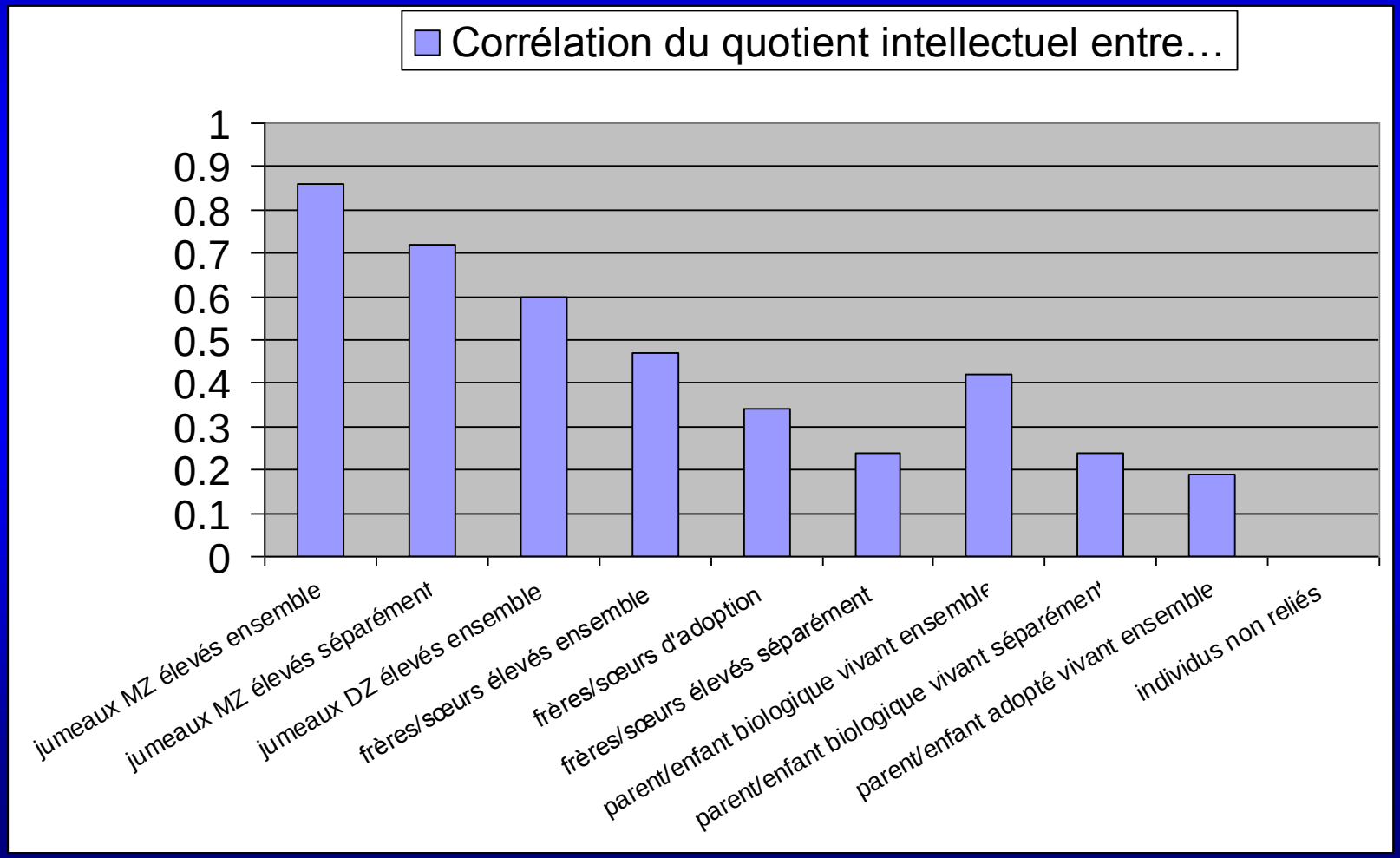
(Scarr, 1992, *Child Development*)





Corrélations du QI entre différentes paires d'apparentés

(Bouchard & McGue, 1981, *Science*; Loehlin, 1989, *American Psychologist*)



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IMMEDIATE COMMUNICATION

Genome-wide association studies establish that human intelligence is highly heritable and polygenic

G Davies[1], A Tenesa[2,3], A Payton[4], J Yang[5], SE Harris[6,7], D Liewald[1,7], X Ke[8], S Le Hellard[9], A Christoforou[9], M Luciano[1,7], K McGhee[1], L Lopez[1,7], AJ Gow[1,7], J Corley[1], P Redmond[1], HC Fox[10], P Haggarty[11], LJ Whalley[10], G McNeill[10], ME Goddard[12,13], T Espeseth[14], AJ Lundervold[15], I Reinvang[14], A Pickles[16], VM Steen[9,17], W Ollier[4], DJ Porteous[6,7], M Horan[18], JM Starr[7,19], N Pendleton[18], PM Visscher[5,7,20] and IJ Deary[1,7,20]

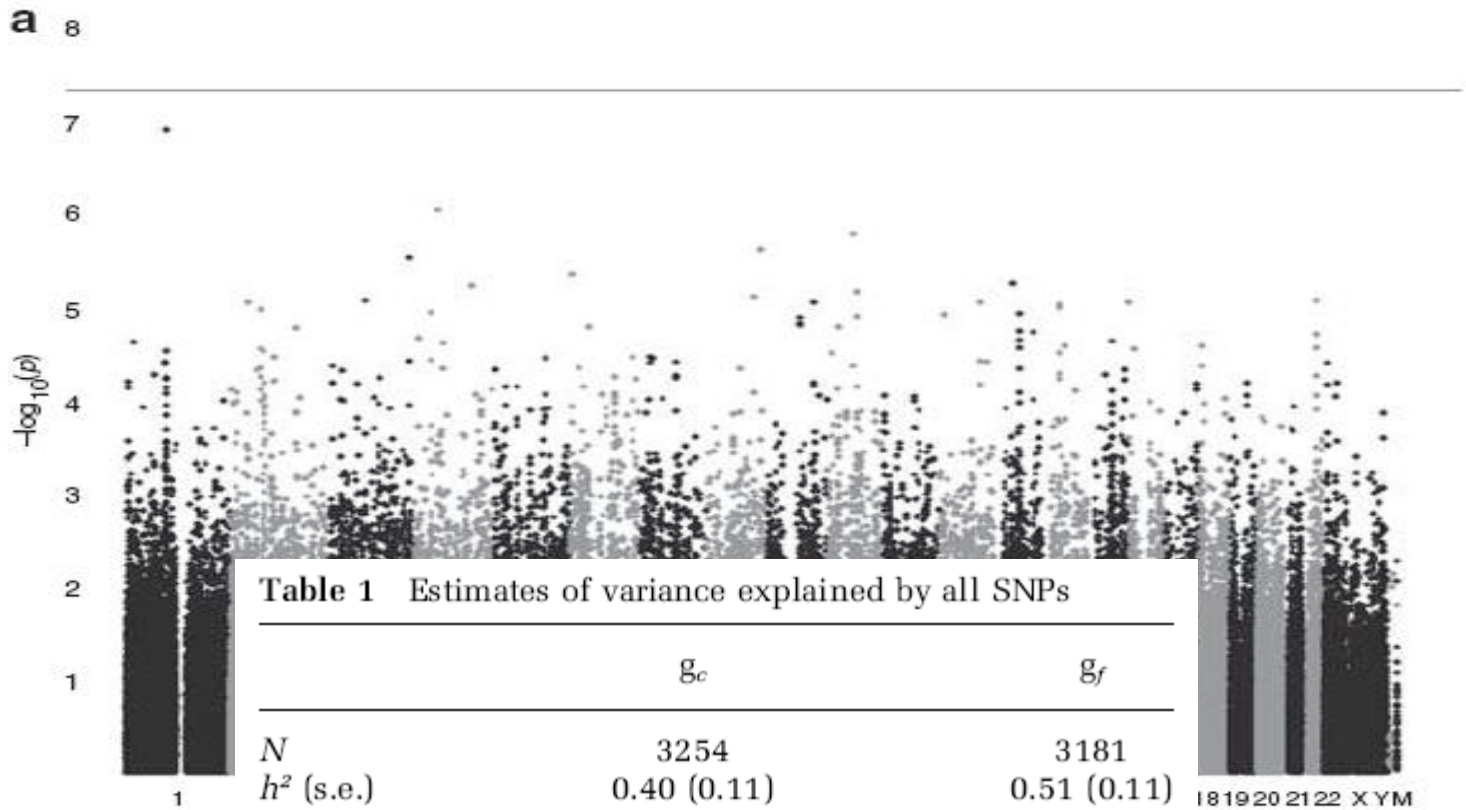


Table 1 Estimates of variance explained by all SNPs

	g_c	g_f
N	3254	3181
h^2 (s.e.)	0.40 (0.11)	0.51 (0.11)
P-value	5.7×10^{-5}	1.2×10^{-7}

Génétique et déficience intellectuelle (QI<70) (Chelly et al. 2006 Eur. J. Hum. Genet.)

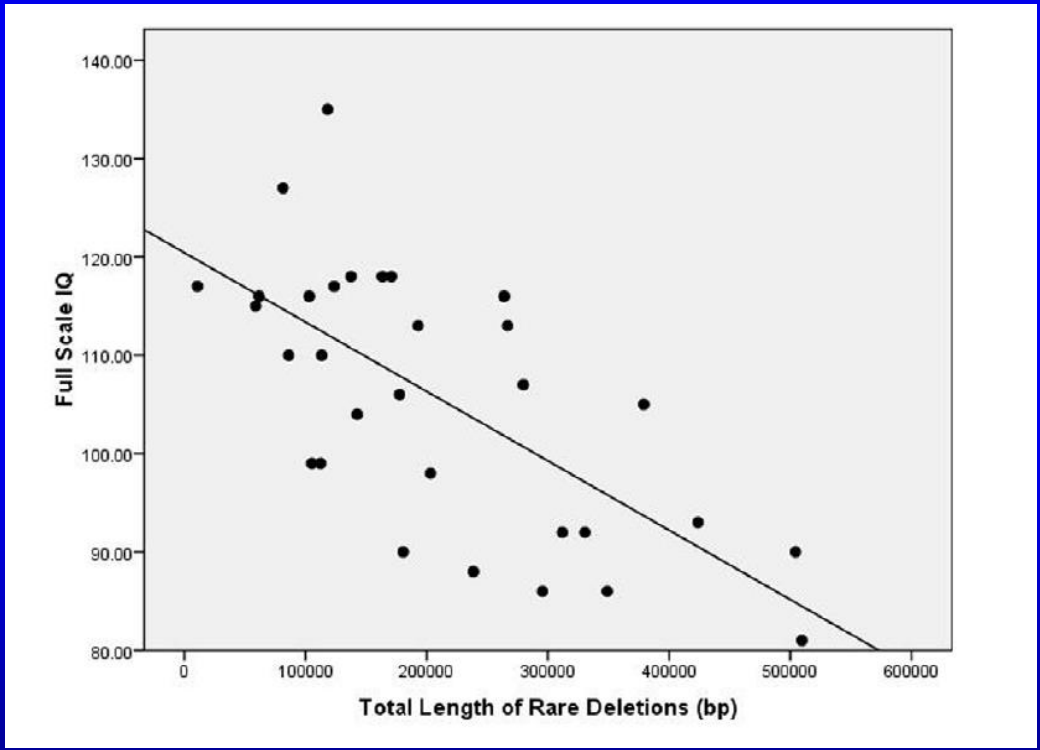
- Environ 300 gènes identifiés, incluant:
- Gènes influençant la taille du cerveau (MCPH1, ASPM…)
- Gènes influençant la migration neuronale (LIS1, DCX, RELN, FLNA…)
- Gènes influençant le développement et le fonctionnement des synapses (FMR1, NLGN4…)
- Facteurs de transcription, gènes de la signalisation cellulaire, de la neurotransmission…
- Non spécifiques au cerveau (ex: PAH).
- Mais pas d'effet connu de ces gènes sur les variations normales de l'intelligence…

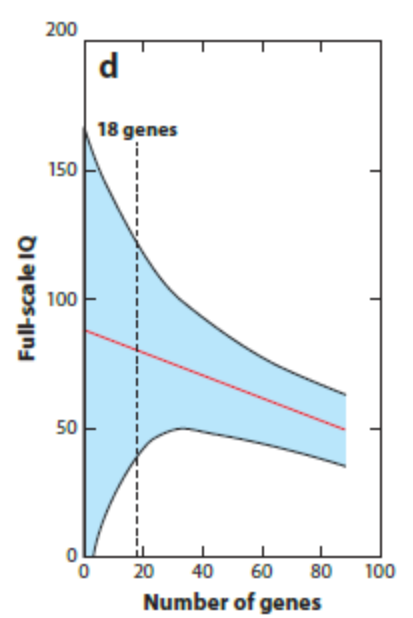
OPEN ACCESS Freely available online PLoS one

Rare Copy Number Deletions Predict Individual Variation in Intelligence

Ronald A. Yeo[1]*, Steven W. Gangestad[1], Jingyu Liu[2,3], Vince D. Calhoun[2,3], Kent E. Hutchison[1,2,4]

Huguet et al. (2013)
Ann. Rev. Genomics…





overlapping with de novo CNVs

Facteurs environnementaux influençant le QI: l'effet Flynn

Flynn, J. R. (1987). Massive gains in 14 nations: What IQ tests really measure. Psychological Bulletin, 101, 171-191.

- Au cours du 20ème siècle, les scores de QI ont progressé d'environ 3 points par décennie.
- Pourquoi?
  - Nutrition
  - Évitement de maladies affectant le développement du cerveau
  - Environnement intellectuel des enfants: garde collective, interactions adultes/enfants, télévision, jeux… (?)
- Contradictoire avec des effets génétiques importants?
  - Non bien sûr…

Un exemple: l'allaitement maternel

Mortensen, E. L., Michaelsen, K. F., Sanders, S. A., & Reinisch, J. M. (2002). The association between duration of breastfeeding and adult intelligence. *Jama*, *287*(18), 2365-2371.

Table 3. Observed and Adjusted Means for Intelligence Test Scores in Relation to Duration of Breastfeeding*

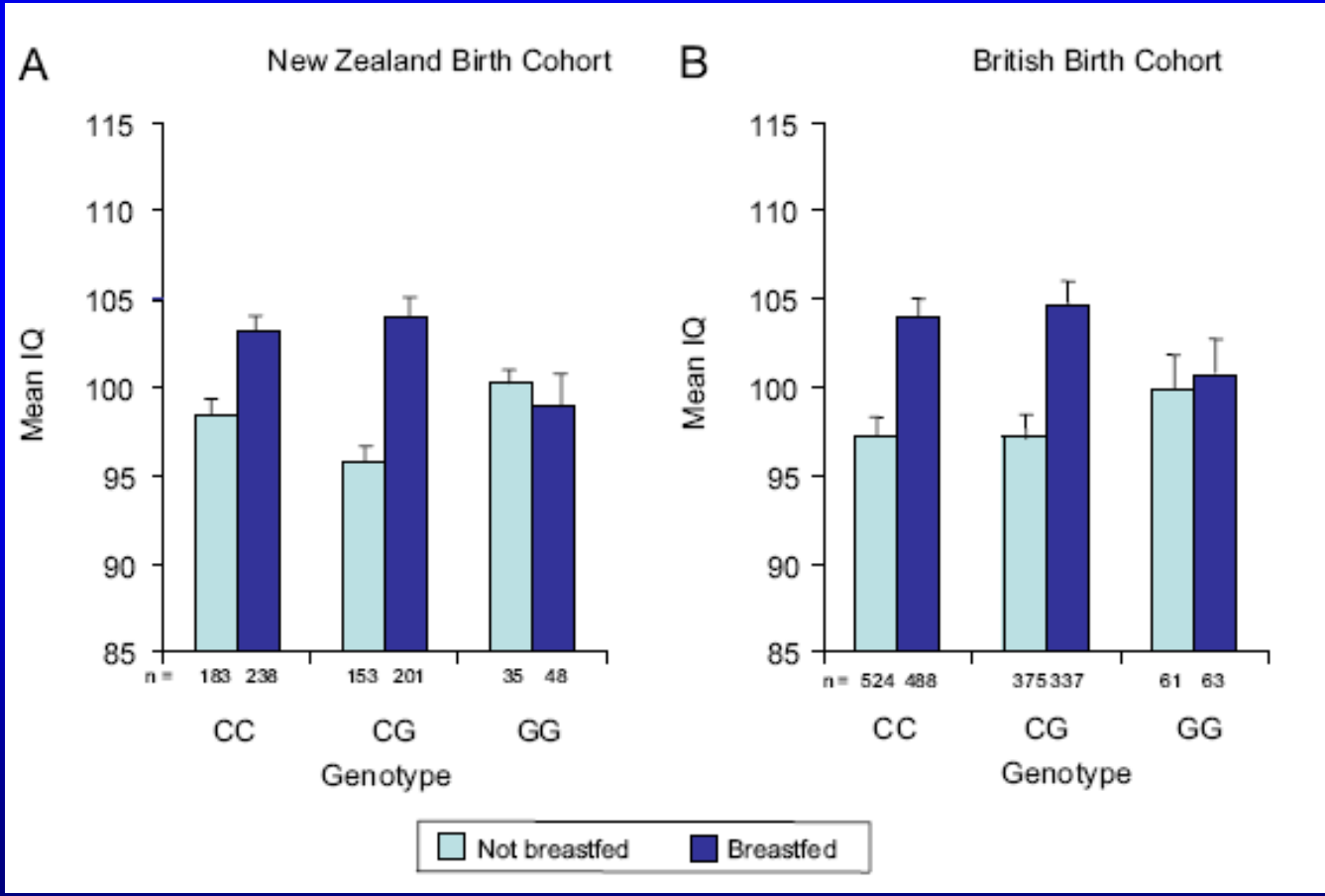
	Duration of Breastfeeding, mo					*P* Value
	≤1	2-3	4-6	7-9	>9	
WAIS Verbal IQ						
Unadjusted mean (SD)	98.2 (16.0)	101.7 (14.9)	104.0 (15.7)	108.2 (13.3)	102.3 (15.2)	<.001
Adjusted mean	99.7	102.3	102.7	105.7	103.0	.007
WAIS Performanc						
Unadjusted mean (SD)					(14.9)	<.001
Adjusted mea					.4	.02
WAIS Full Scale IQ						
Unadjusted mean (SD)	98.1 (15.9)	101.3 (15.2)	103.3 (15.7)	108.2 (13.1)	102.8 (14.4)	<.001
Adjusted mean	99.4	101.7	102.3	106.0	104.0	.003
BPP						
Unadjusted mean (SD)	36.9 (11.3)	39.0 (11.1)	40.8 (11.2)	43.1 (11.0)	40.2 (12.3)	<.001
Adjusted mean	38.0	39.2	39.9	40.1	40.1	.01

Par quel mécanisme??

*The significance levels for both the unadjusted and adjusted means refer to the overall F tests of significance of mean differences between the 5 breastfeeding categories. The adjusted means for the Børge Priens Prøve (BPP) test are adjusted for marital status, social status, breadwinner's education, mother's height, mother's age, mother's weight gain during pregnancy, mother's cigarette consumption during the third trimester, number of pregnancies, estimated gestational age, birth weight, birth length, an index of pregnancy complications, and an index of delivery complications. The adjusted means for the Wechsler Adult Intelligence Scale (WAIS) are also adjusted for effects of sex and medication exposure.

Moderation of breastfeeding effects on the IQ by genetic variation in fatty acid metabolism (Caspi et al. 2007 PNAS)

- FADS1, FADS2 on 11q12: fatty acid desaturases
- SNP rs174575 in 1st intron of FADS2



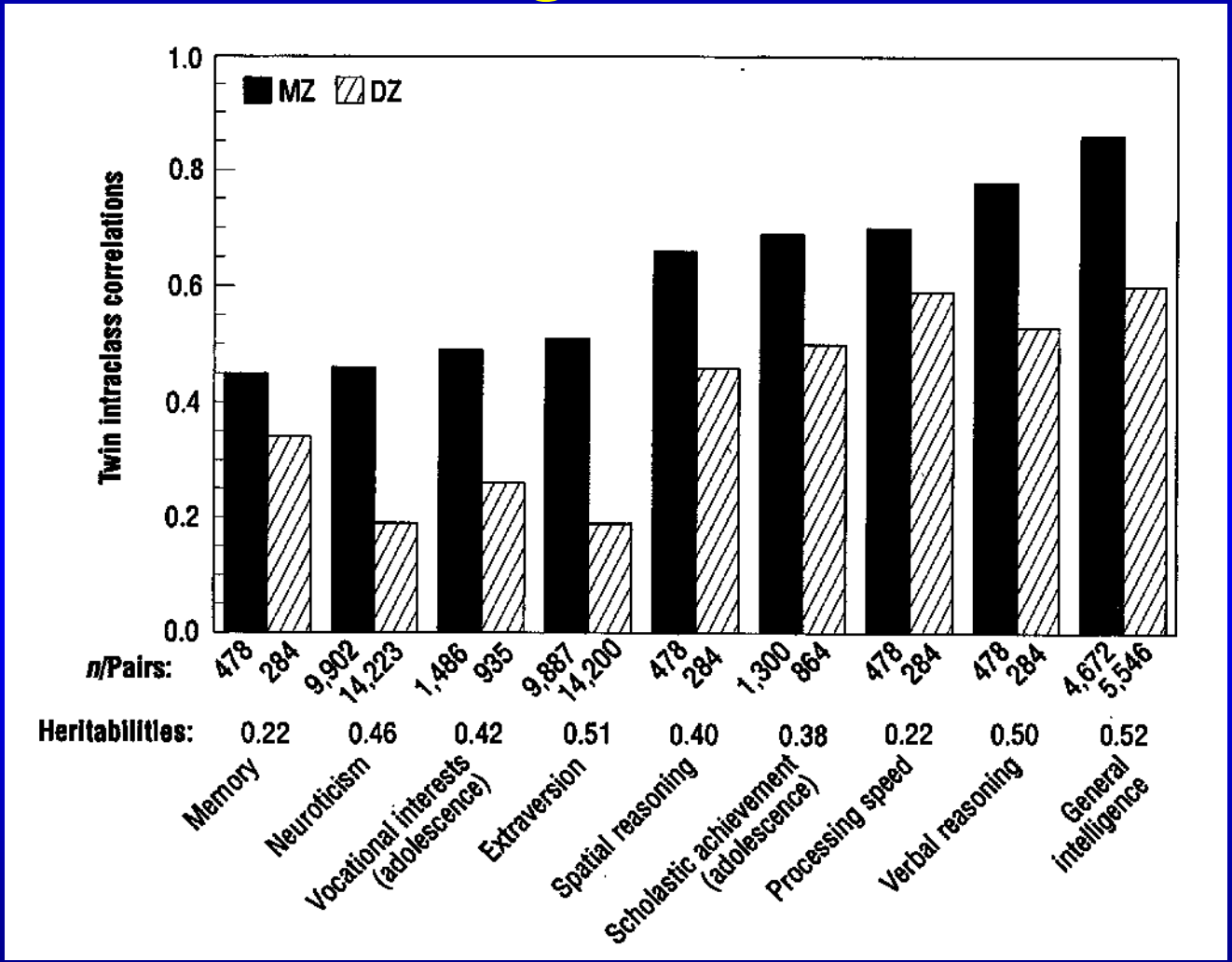
Conclusions

- Les influences génétiques, même fortes, n’excluent pas les influences environnementales.
- Les influences environnementales, mêmes prépondérantes, sont malgré tout modérées par des facteurs génétiques…

Individual differences in cognitive abilities

Examples of more specific cognitive functions

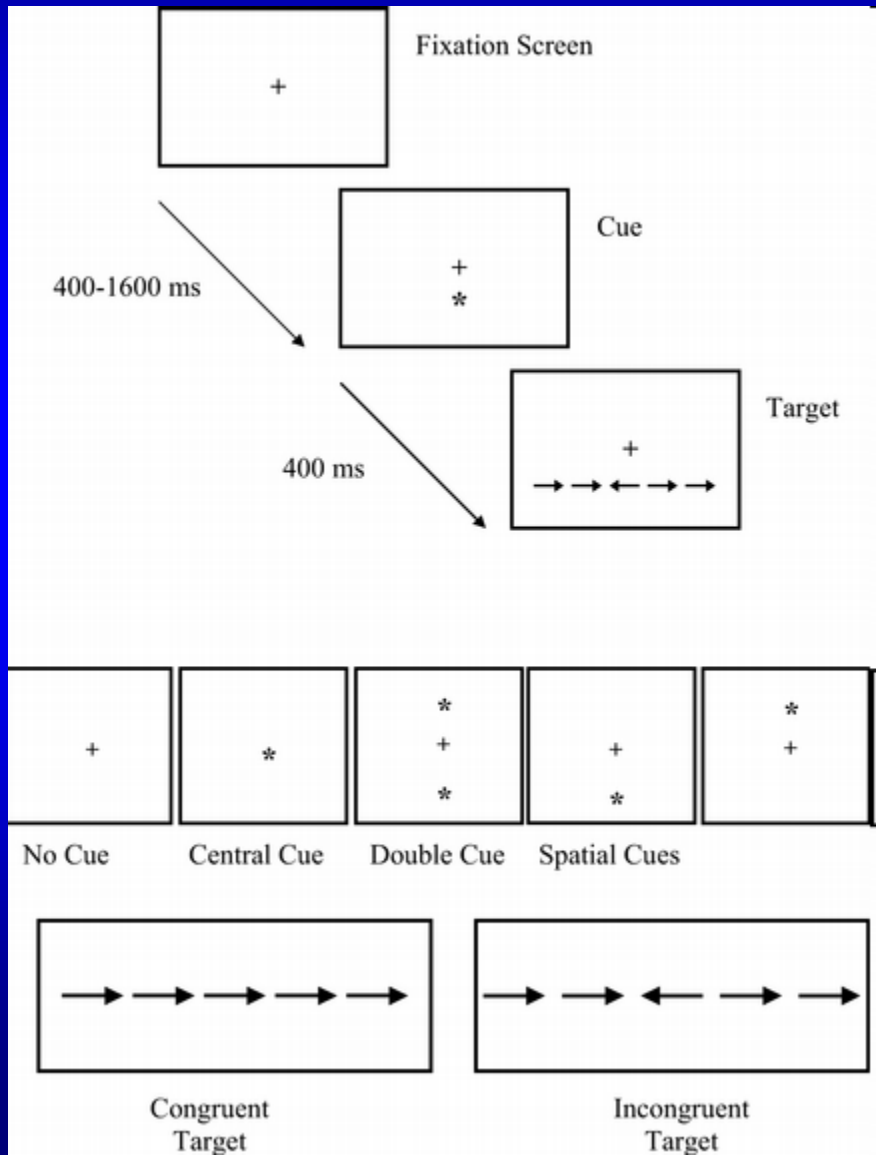
Etudes de jumeaux: corrélation des fonctions cognitives



Plomin, R., Owen, M. J., & McGuffin, P. (1994). The genetic basis of complex human behaviors. *Science, 264*(5166), 1733-1739.

Dopamine, attention et fonctions exécutives

- Les gènes DRD4, MAOA et COMT modulent les capacités attentionnelles d'adultes sains (tâches de résolution de conflit) (Posner et al.)



Dopamine, attention et fonctions exécutives

- Un allèle de DRD2 module la capacité à apprendre à partir de ses propres erreurs, et les activations fonctionnelles correspondantes (Klein et al. 2007)
- Un allèle de COMT module la performance dans des tâches de mémoire de travail et de flexibilité mentale.
- COMT a également été associée au QI, dans certaines études.

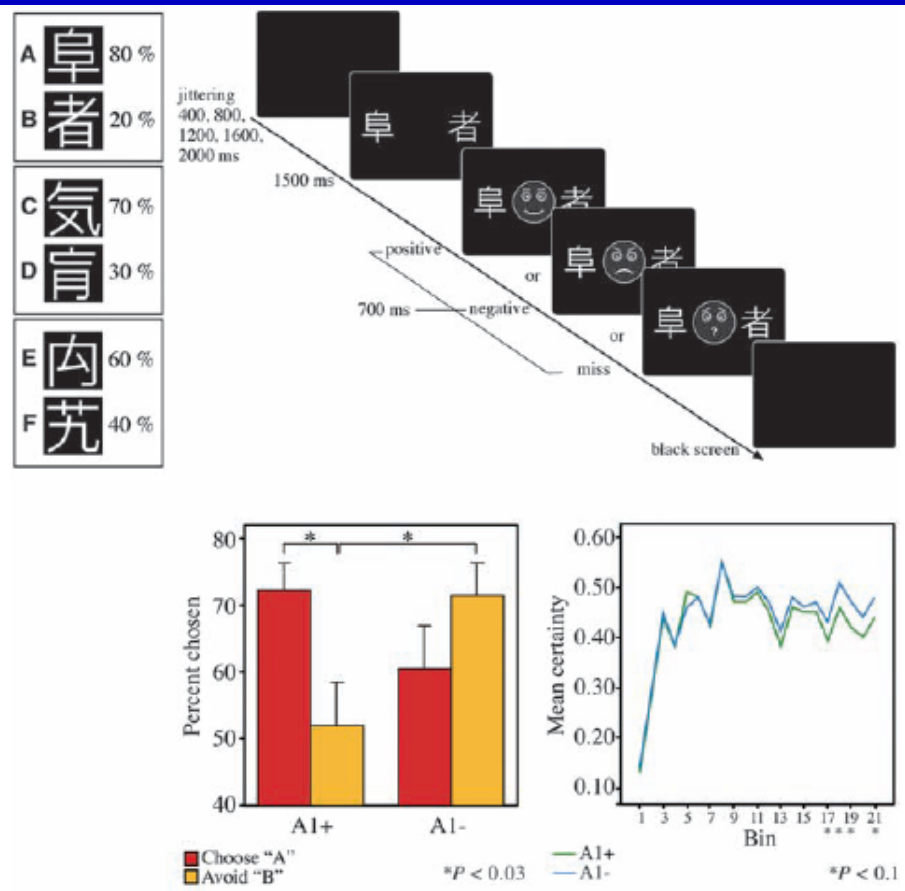
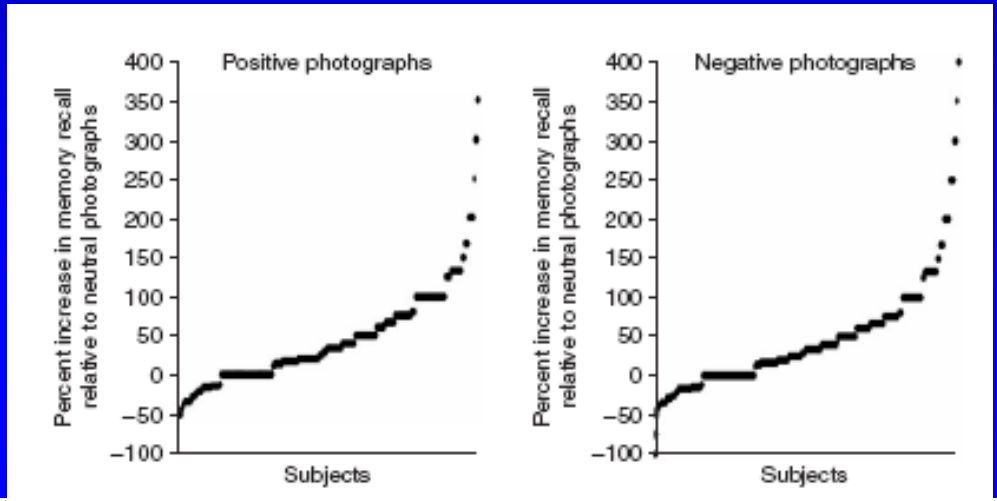
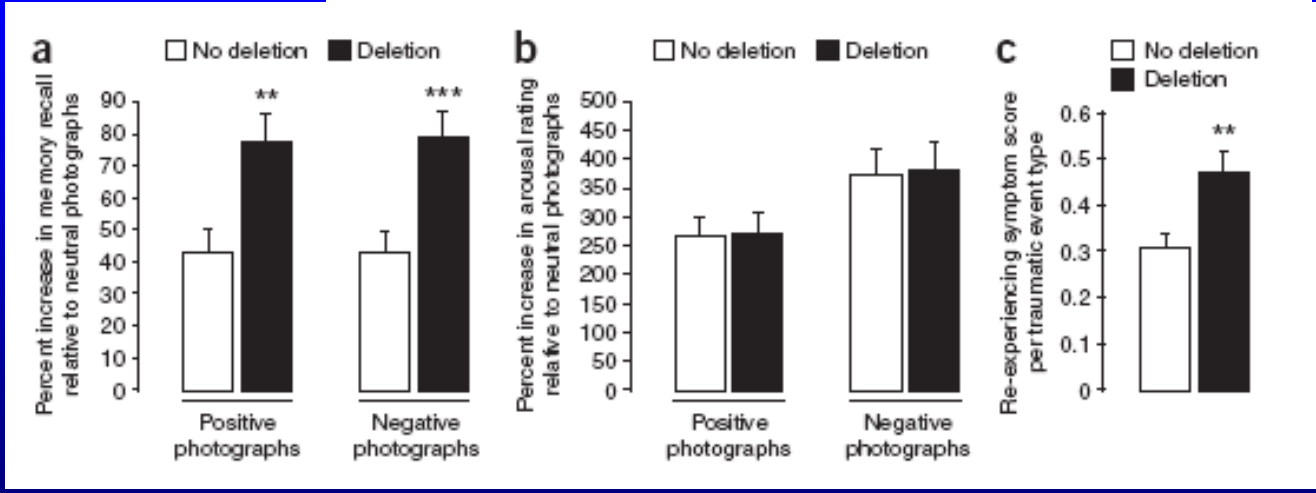


Fig. 1. Probabilistic learning task, behavioral and computational results. (Top) Stimuli, reward probabilities (percent positive feedback), and schematic trial sequence of the probabilistic learning task (*2*). (Bottom, left) Result of the behavioral post test: Choosing the good symbol (A) and avoiding the bad one (B) differs between the two genetic groups (group × selection interaction: $F_{1,24} = 8.1$, $P = 0.009$). (Bottom, right) Certainty of the given response resulting from the computational model, binned into bins of 20 trials each and differentiated between the two genetic groups.

Influences génétiques sur la mémoire

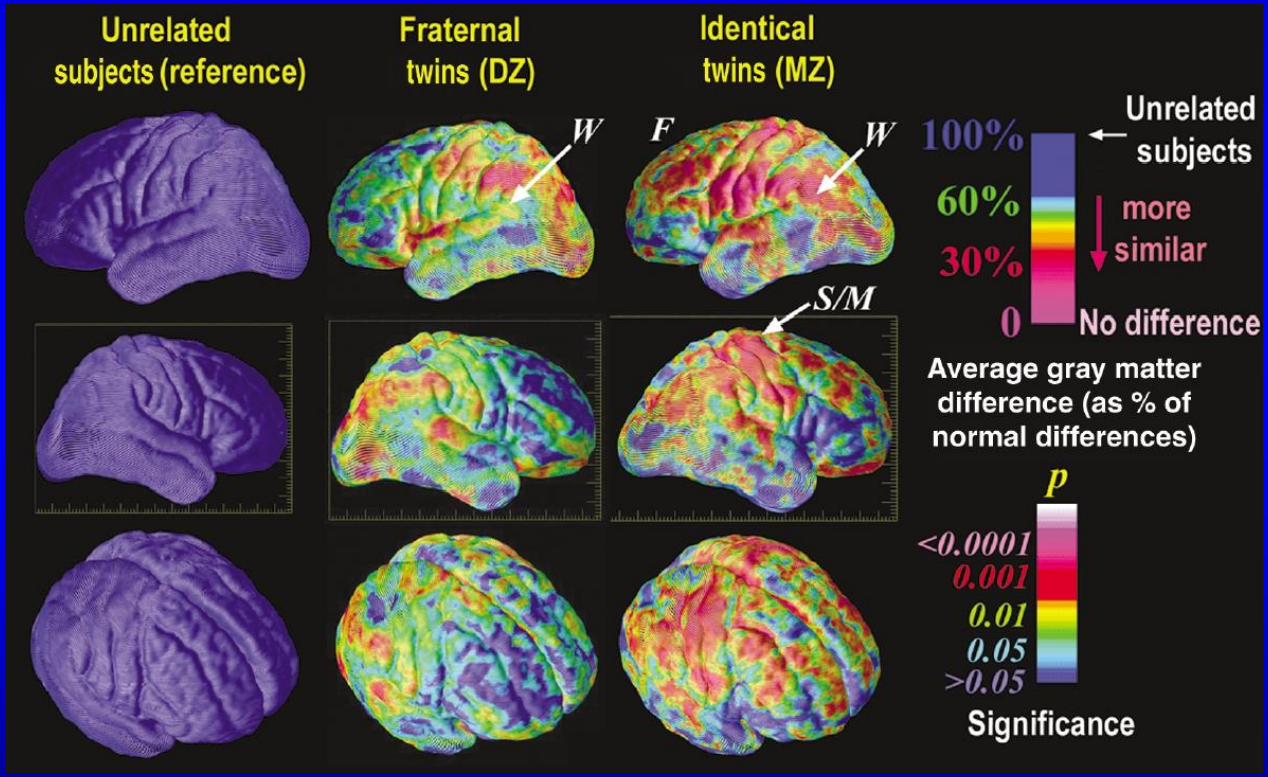
- 5-HT2a associé à la mémoire épisodique (verbale et spatiale, rappel à 5 min. et 24h) (de Quervain et al. 2003).
- KIBRA associé à la mémoire verbale épisodique et aux activations de l'hippocampe (Papassotiropoulos et al. 2006).
- ADRA2B (adrenoreceptor) associé à la mémoire émotionnelle (description de photos) et aux symptomes de stress post-traumatique (de Quervain et al. 2007)
- Et bien d'autres (de Quervain et al. 2006).





Genetic influences on brain structure and function

Héritabilité des volumes de matière grise et blanche



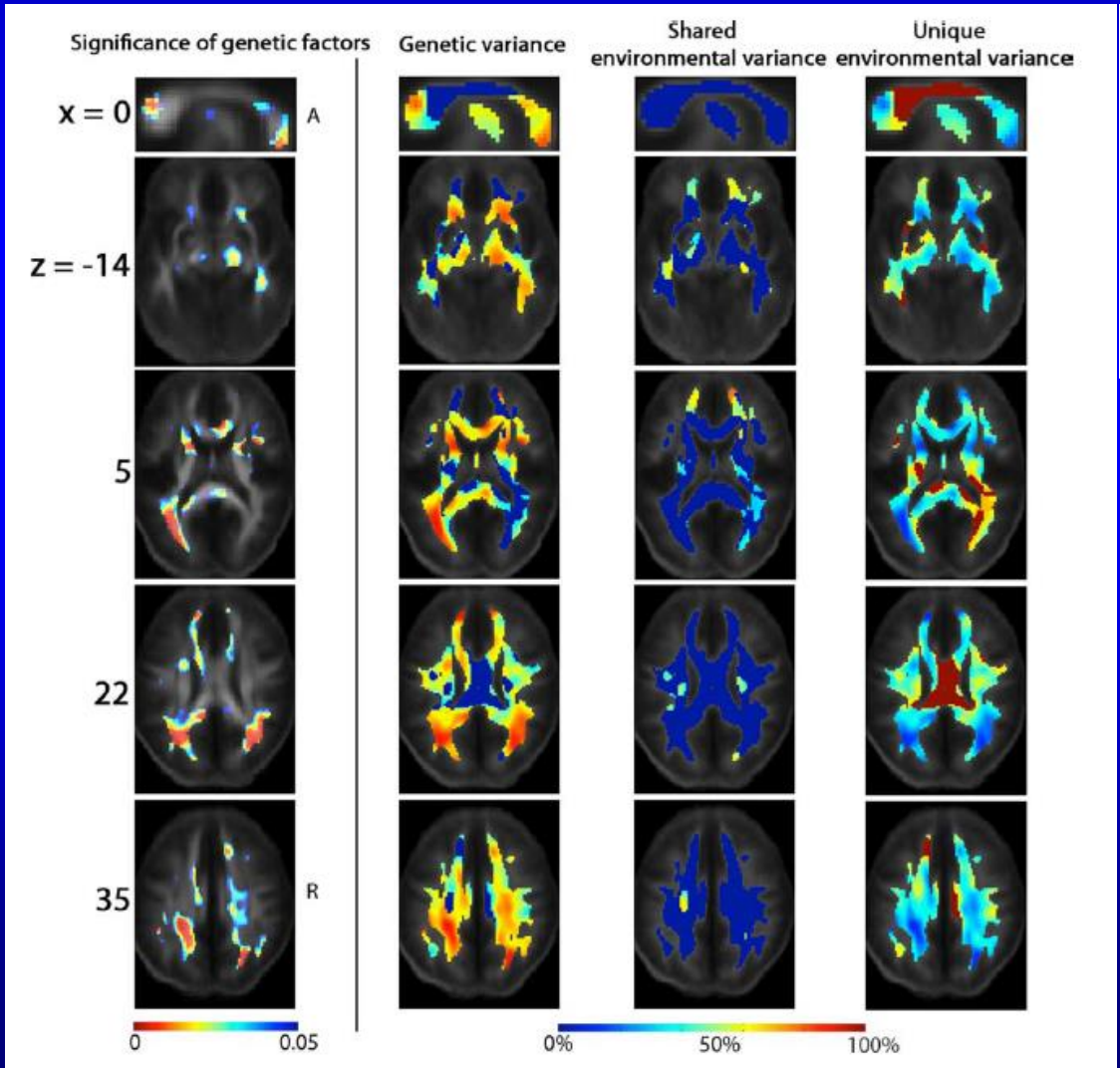
Structure	a^2
Total cerebral	.89 (.67 .92)
Total gray matter	.82 (.50 .87)
Total white matter	.85 (.56 .90)
Frontal gray matter	.77 (.36 .83)
Frontal white matter	.84 (.52 .89)
Total frontal	.84 (.56 .89)
Parietal gray matter	.78 (.41 .86)
Parietal white matter	.85 (.63 .90)
Total parietal	.86 (.62 .90)
Temporal gray matter	.80 (.45 .86)
Temporal white matter	.82 (.40 .89)
Total temporal	.88 (.60 .91)
Caudate Nucleus	.80 (.56 .85)
Corpus callosum	.85 (.41 .89)
Lateral ventricles	.31 (.00 .67)
Total cerebellum	.49 (.13 .83)

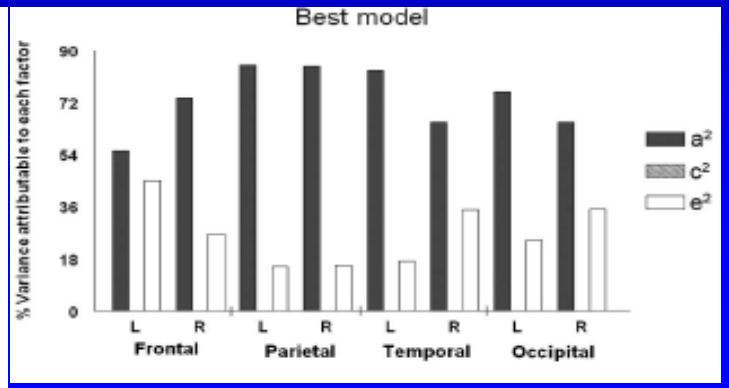
Brackets indicate 95% confidence intervals.

Thompson, P. M., et al. (2001). Genetic influences on brain structure. *Nat Neurosci, 4*(12), 1253-1258.
Wallace, G. L., et al. (2006). *Journal of Child Psychology and Psychiatry, 47*(10), 987-993.

Heritability of white matter connectivity

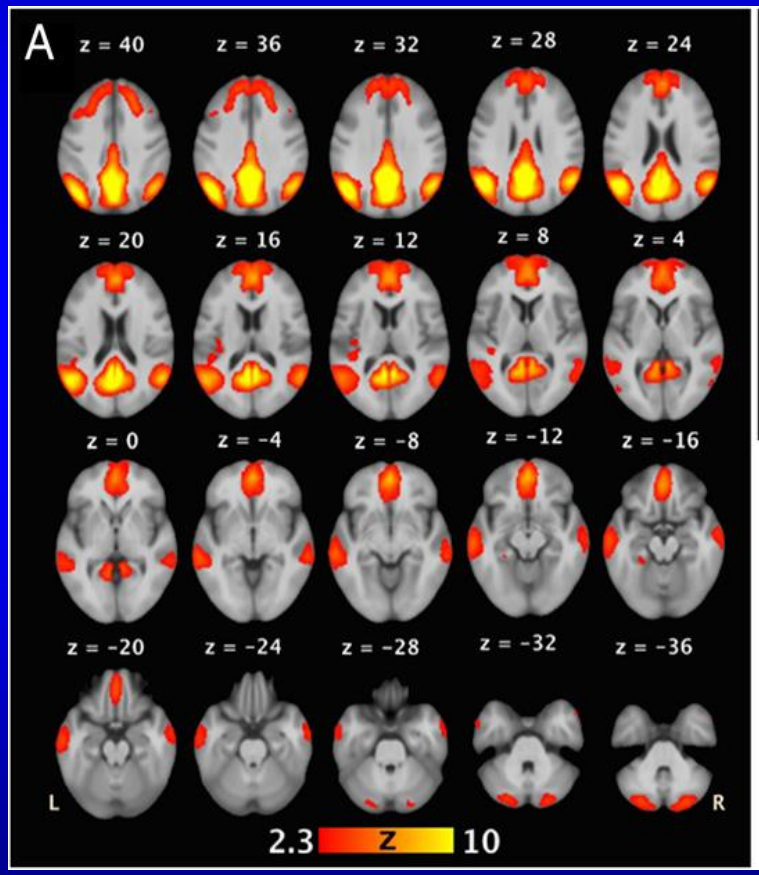
(Chiang et al. 2009 *J Neurosci)*





Heritability of the default mode network

Glahn, D. C., et al. (2010). *PNAS*



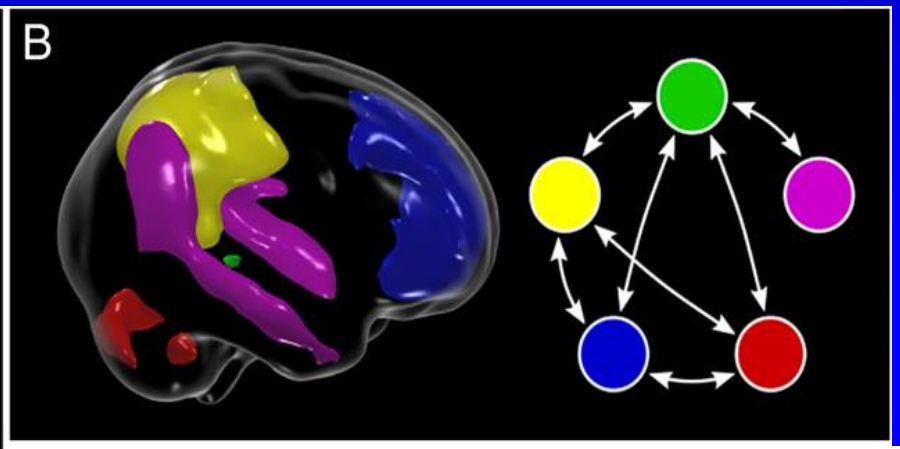
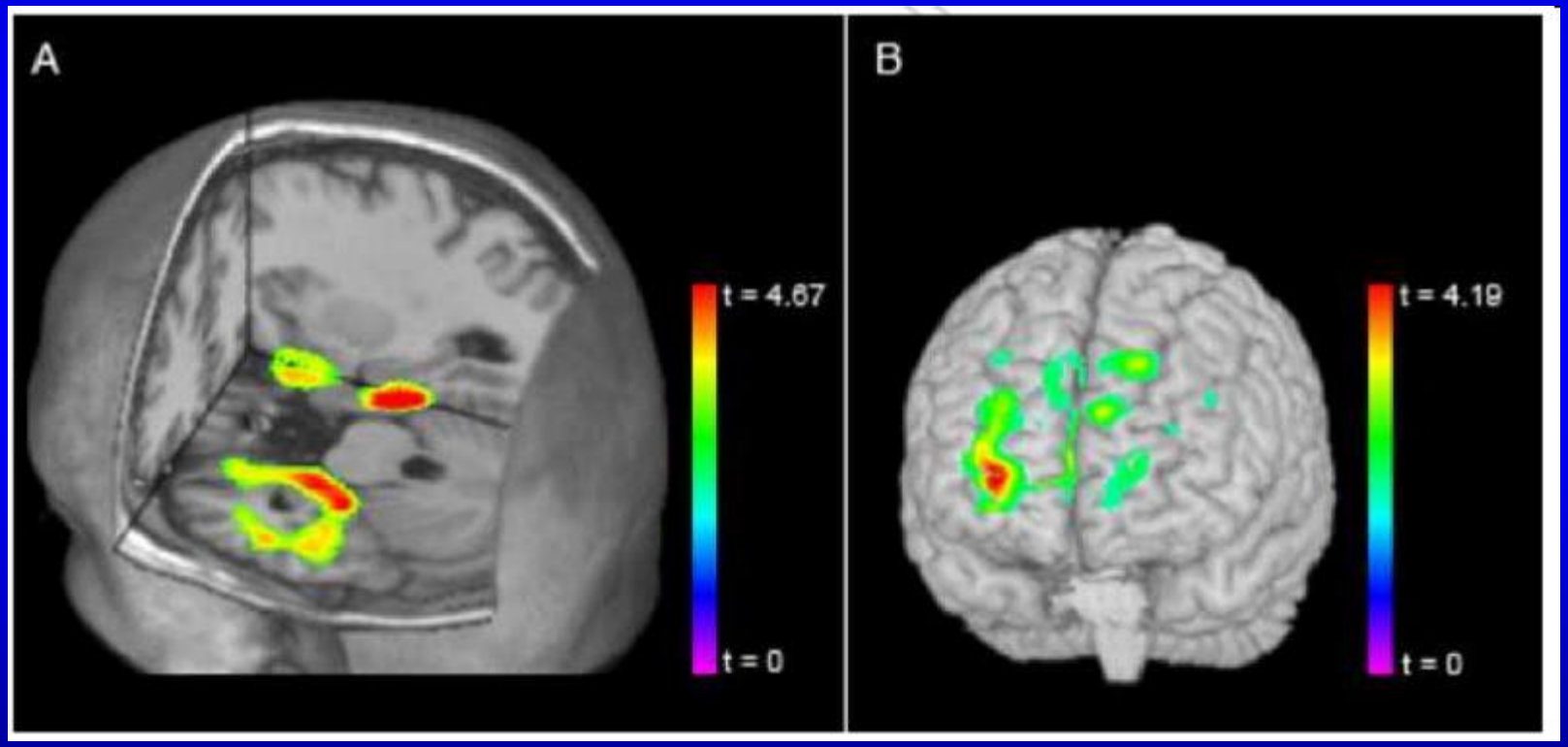


Table 2. Heritability estimates for regions within the default mode

	Functional connectivity		Gray-matter density	
Region*	Heritability†	*P* value‡	Heritability†	*P* value‡
Posterior cingulate/precuneus	0.423 (0.17)	4.4×10^{-3}	0.623 (0.16)	6.8×10^{-5}
Medial prefrontal cortex	0.376 (0.15)	3.8×10^{-3}	0.631 (0.15)	5.3×10^{-6}
Left temporal–parietal region	0.331 (0.19)	3.1×10^{-2}	0.387 (0.21)	3.1×10^{-2}
Right temporal–parietal region	0.420 (0.16)	3.5×10^{-3}	0.365 (0.21)	3.4×10^{-2}
Left cerebellum	0.104 (0.13)	2.0×10^{-1}	0.493 (0.15)	4.9×10^{-4}
Right cerebellum	0.304 (0.16)	1.6×10^{-2}	0.596 (0.14)	1.6×10^{-5}
Cerebellar tonsil	0.219 (0.19)	1.1×10^{-1}	0.271 (0.16)	3.2×10^{-2}
Left parahippocampal gyrus	0.273 (0.14)	1.7×10^{-2}	0.420 (0.18)	7.5×10^{-3}

*Bolded figures are significant at 5% FDR.
†Estimated heritability, h2 (SE).
‡*P* value for the heritability estimate.

Impact of interacting functional variants in COMT on regional gray matter volume in human brain. Honea, R., et al. (2009). *Neuroimage*



A. Whole brain VBM results overlaid on MRICRON 3-D mean 154 brain showing significant decreases in volume in a cluster of voxels including the left hippocampus and parahippocampal gyrus in val-allele carriers and val homozygotes relative to met homozygotes. **B.** Overlay demonstrating a trend for volume reductions in met-carriers in (val/val > val/met > met/met) an ROI in the DLPFC (including BA 9, 10, 45, and 46).

Common *Kibra* Alleles Are Associated with Human Memory Performance

Andreas Papassotiropoulos,[1,3]*† Dietrich A. Stephan,[3]*† Matthew J. Huentelman,[3] Frederic J. Hoerndli,[1] David W. Craig,[3] John V. Pearson,[3] Kim-Dung Huynh,[1] Fabienne Brunner,[1] Jason Corneveaux,[3] David Osborne,[4] M. Axel Wollmer,[1] Amanda Aerni,[1] Daniel Coluccia,[1] Jürgen Hänggi,[1] Christian R. A. Mondadori,[1] Andreas Buchmann,[1] Eric M. Reiman,[3,6] Richard J. Caselli,[5] Katharina Henke,[1] Dominique J.-F. de Quervain[1,2]

Human memory is a polygenic trait. We performed a genome-wide screen to identify memory-related gene variants. A genomic locus encoding the brain protein KIBRA was significantly associated with memory performance in three independent, cognitively normal cohorts from Switzerland and the United States. Gene expression studies showed that *KIBRA* was expressed in memory-related brain structures. Functional magnetic resonance imaging detected *KIBRA* allele–dependent differences in hippocampal activations during memory retrieval. Evidence from these experiments suggests a role for KIBRA in human memory.

Table 1. Association of SNPs rs17070145 (*KIBRA*) and rs6439886 (*CLSTN2*) with verbal episodic memory in Swiss cohort 1. Genotype calls of eight subjects were not considered for analysis due to low-quality pyrograms for rs17070145. Means with common superscripts are significantly different according to multifactorial analysis of variance. Data are means ± SEM.

	n	No. of words recalled		
		Immediately	After 5 min	After 24 hours
rs17070145				
CC	164	23.6 ± 0.3	7.6±0.2*	6.7 ± 0.2†
CT/TT	169	24.1 ± 0.3	9.4±0.2*	8.0 ± 0.2†
rs6439886				
TT	265	23.9 ± 0.2	8.4±0.2‡	7.3 ± 0.2§
TC/CC	76	24.2 ± 0.4	9.8±0.4‡	8.4 ± 0.4§

*$P = 0.000004$ †$P = 0.0008$ ‡$P = 0.002$ §$P = 0.022$

Table 2. Association of SNPs rs17070145 (*KIBRA*) and rs6439886 (*CLSTN2*) with episodic memory in the U.S. population. The SRT was completed by 200 participants (98 CC carriers and 102 CT and TT carriers of rs17070145). Genotype calls of seven participants were not considered for analysis because of low-quality pyrograms for rs6439886. Means with common superscripts are significantly different according to multifactorial analysis of variance. Data are means ± SEM.

	n	No. of items recalled		
		Immediately (AVLT)	After 30 min (AVLT)	Free recall task (SRT)
rs17070145				
CC	126	9.4 ± 0.3	8.5±0.3*	83.7 ± 1.2†
CT/TT	130	10.0 ± 0.3	9.7±0.3*	90.3 ± 1.1†
rs6439886				
TT	185	9.7 ± 0.2	9.1±0.2	88.4 ± 0.9
TC/CC	64	9.9 ± 0.4	9.2±0.4	88.9 ± 1.6

*$P = 0.004$ †$P = 0.00005$

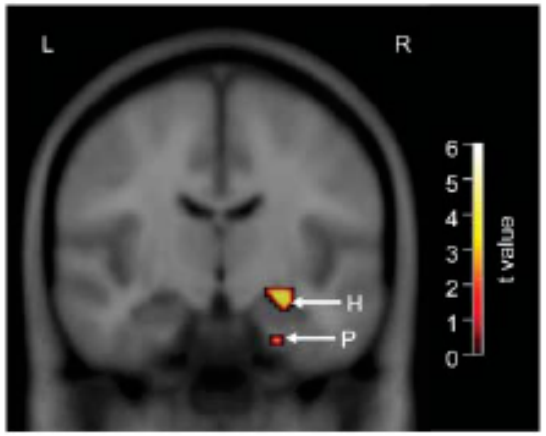


Fig. 3. Significant *KIBRA* allele–dependent differences in hippocampal activation as measured with fMRI. Activations are significantly increased in the hippocampus in noncarriers ($n = 15$) of the T allele of SNP rs17070145 than in the hippocampus of T allele carriers ($n = 15$). Activations from all 30 individuals were overlaid on a coronal section of a T1-weighted magnetic resonance image of SPM2 and displayed in color-coded t values. Threshold: $P < 0.001$. H, hippocampus; P, parahippocampal gyrus; L, left side of the brain; R, right side of the brain.

Conclusions

The bottom line about innateness

- Things are not either innate, or acquired.
- These words do not have sufficiently coherent definitions to be useful in scientific discussions.
- All cognitive abilities and disabilities that have been investigated are *heritable*, i.e. genetically influenced to some extent. This extent is never 100%.
- Therefore, all cognitive abilities and disabilities are also environmentally influenced to a complementary extent.
- No matter the extent of genetic influences, it is always possible to alter the outcome by manipulating environmental influences.
- Strong genetic influences do not imply that the environment doens't matter, that nothing can be done, etc!
- Genes matter, family environment matters, teaching matters, society matters….
- Families and teachers should do their best with every single child.

Sex differences in cognition

Sex differences

biological

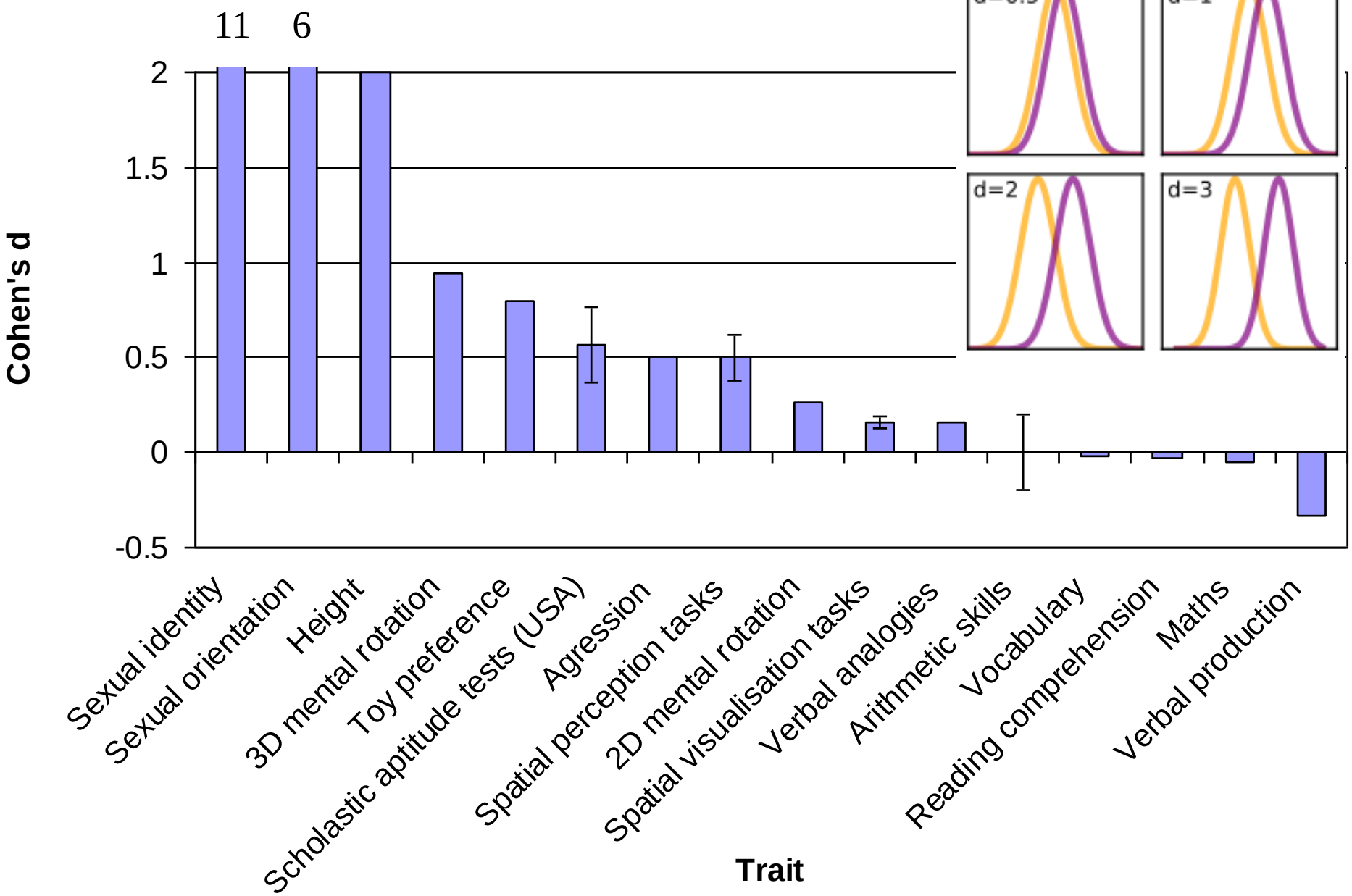
- Sex chromosomes
- Sex organs and reproductive function
- Secondary sexual characters (body size and shape, hair…)
- Hormones
- Brain volume
- Volume/organisation/ functioning of specific brain structures (hypothalamus, amygdala, …)
- Susceptibility to various somatic diseases

cognitive/behavioural

- Sexual identity
- Sexual orientation
- Sexual motivation & behaviour
- Criteria for partner preferences
- Parental motivation and behaviour
- Social behaviour
- Aggression, violence, criminality
- Motor/physical ability
- Language ability
- Social cognitive ability
- Spatial ability
- Emotional processing
- Susceptibility to neurodevelopmental and psychiatric disorders
- Income, high-status positions
- Vocational interests

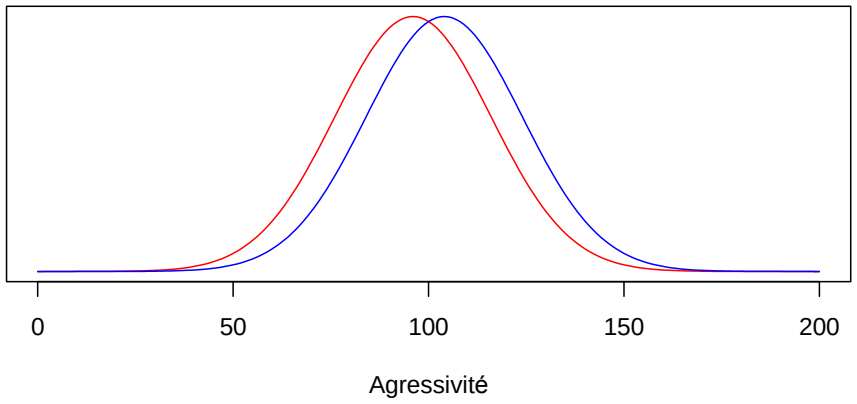
Effect sizes of sex differences

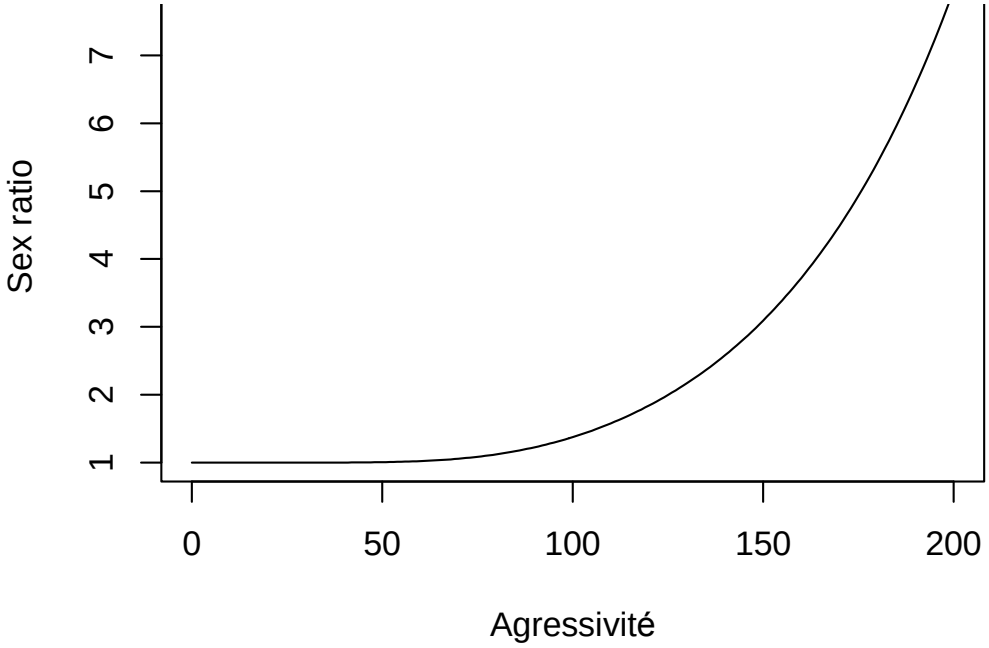
(from Hines 2004)



Sex differences in aggression

Archer 2004 *Rev. Gen. Psych.*





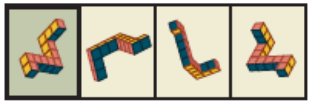
Source:
N. Gauvrit

Sex differences in cognitive ability (Kimura 2003)

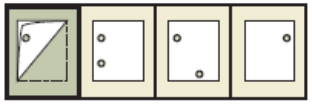
- d=-0.5 – 1
- Equal average IQ
- But slightly different cognitive profiles

Problem-Solving Tasks Favoring Men

Men tend to perform better than women on certain spatial tasks. They do well on tests that involve mentally rotating an object or manipulating it in some fashion, such as imagining turning this three-dimensional object

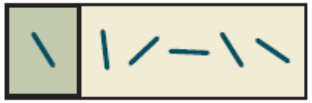


or determining where the holes punched in a folded piece of paper will fall when the paper is unfolded:



Men also are more accurate than women at target-directed motor skills, such as guiding or intercepting projectiles:

They do better at matching lines with identical slopes:



And men tend to do better than women on tests of mathematical reasoning:

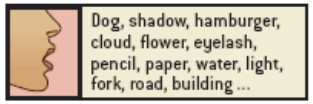
1,100	If only 60 percent of seedlings will survive, how many must be planted to obtain 660 trees?

Problem-Solving Tasks Favoring Women

Women tend to perform better than men on tests of perceptual speed in which subjects must rapidly identify matching items—for example, pairing the house on the far left with its twin:

In addition, women remember whether an object, or a series of objects, has been displaced:

When they are read a story, paragraph or a list of unrelated words, women demonstrate better recall:



Women do better on precision manual tasks—that is, those involving fine-motor coordination—such as placing the pegs in holes on a board:

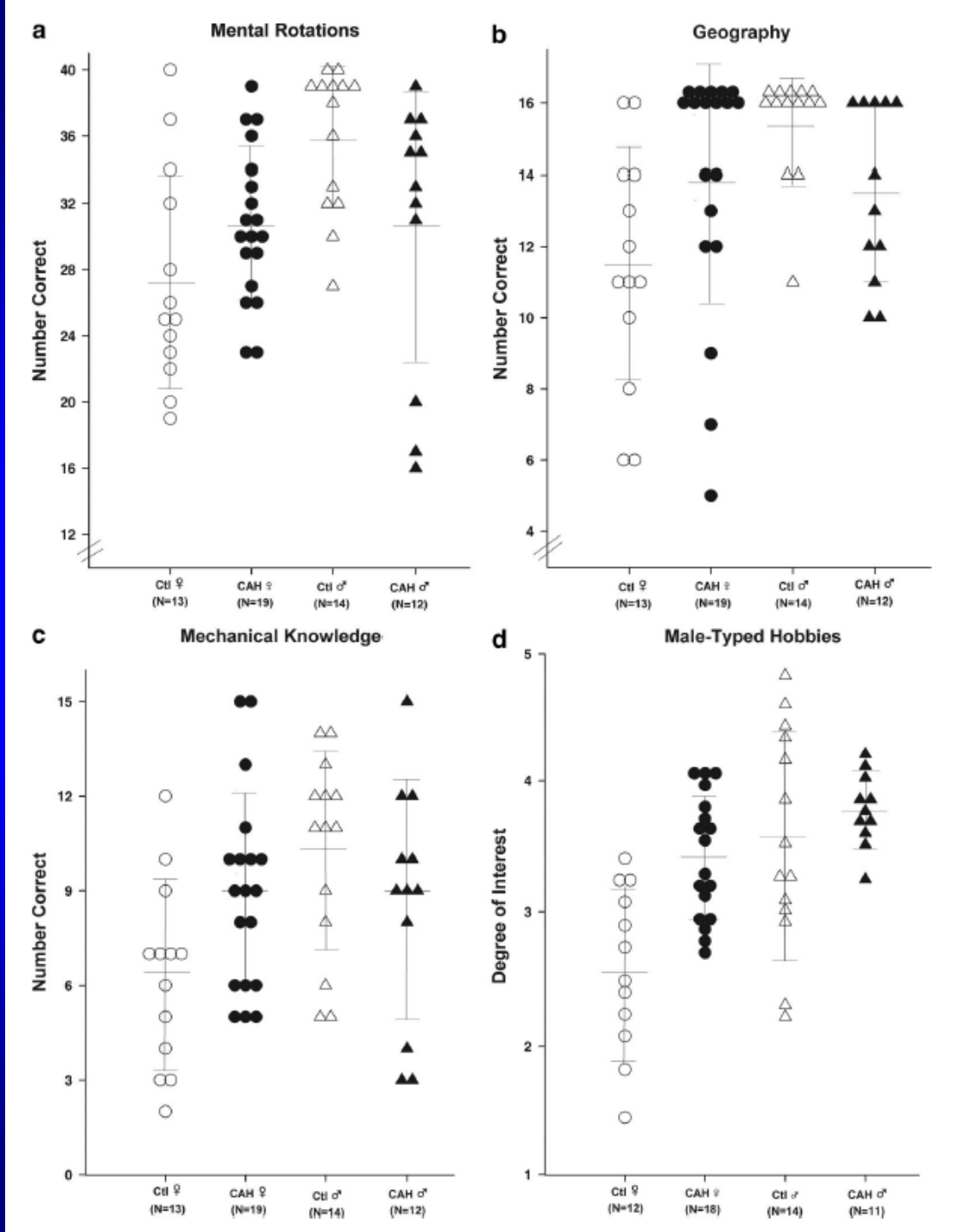
And women do better than men on mathematical calculation tests:

77	$14 \times 3 - 17 + 52$
43	$2\,(15 + 3) + 12 - \frac{15}{3}$

Spatial and mechanical abilities

Berenbaum et al. (2012)

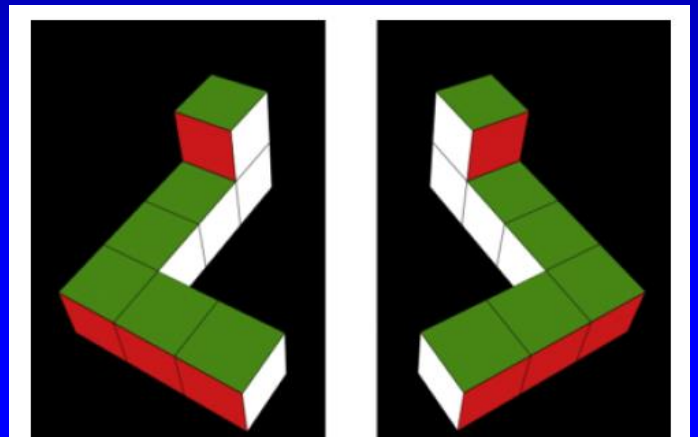
Behavioral Neuroscience

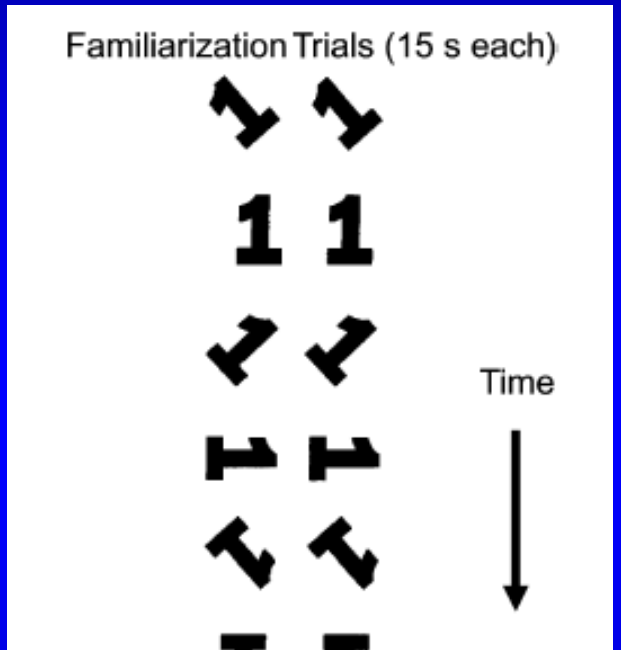


Mental rotation in human infants

Moore & Johnson 2008 *Psych Sci* (5 months old)

Quinn & Liben 2008 *Psych Sci* (3-4 months old)





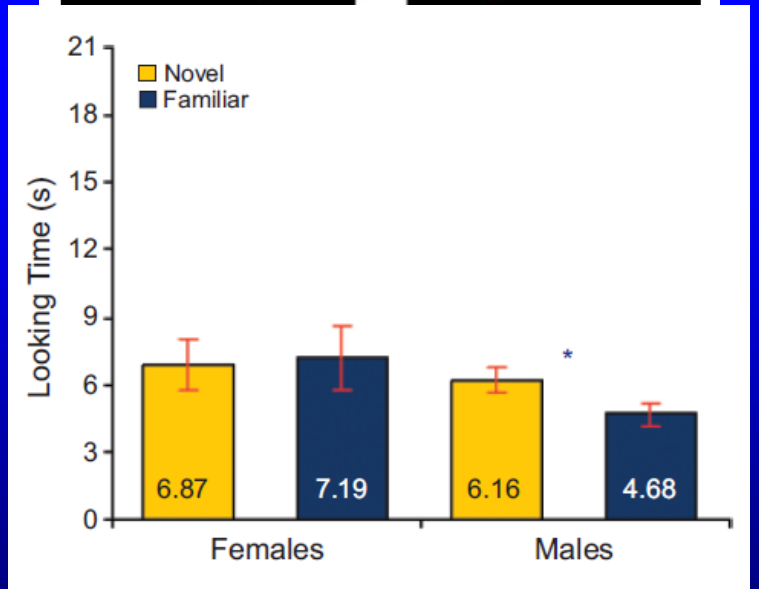


Fig. 2. Five-month-old infants' mean looking times at novel and familiar stimuli. Error bars indicate standard errors of the means, and an asterisk indicates statistical significance, $p < .001$, two-tailed t test.

TABLE 1

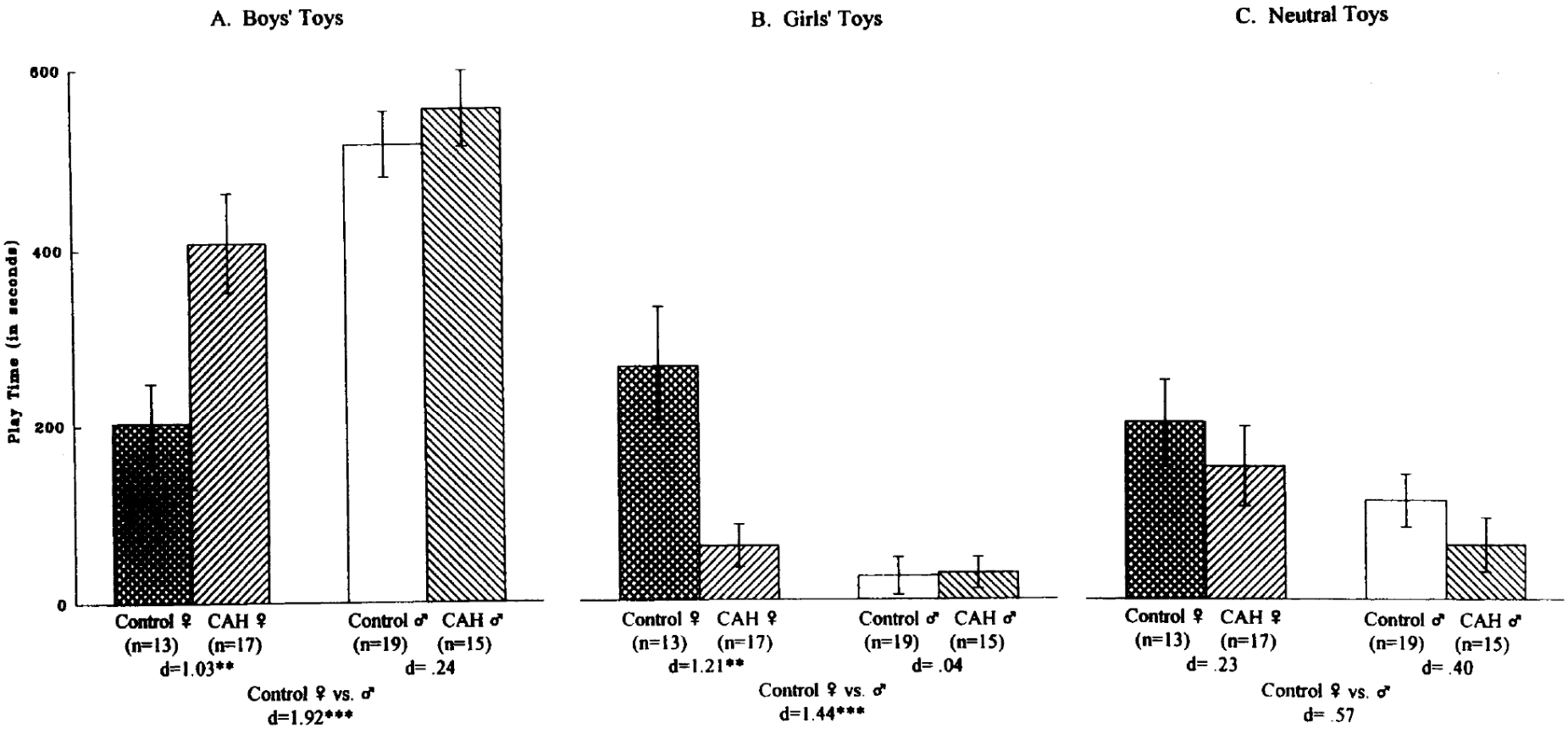
Mean Fixation Times During the Familiarization Trials and Mean Novelty-Preference Scores for the Mirror-Image Stimulus During the Preference Test Trials

	Fixation time (s)				Novelty preference		
	Trials 1–3		Trials 4–6		Score (%)		
Participant group	*M*	*SD*	*M*	*SD*	*M*	*SD*	$t(11)$[a]
Females	7.68	2.82	6.05	2.72	50.20	11.87	0.06
Males	8.07	2.88	6.69	2.22	62.67	6.08	7.22*

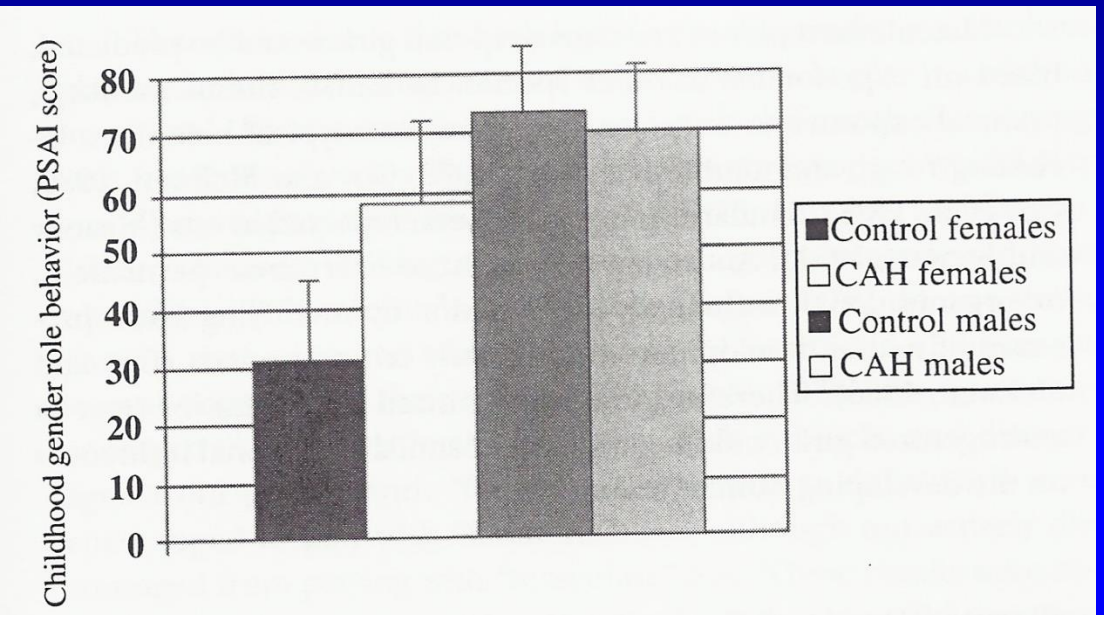
[a]The t tests indicate whether the means differed significantly from chance.
*$p < .001$.

Sex-typed toy preference (d~=0.8)

Berenbaum & Snyder 1995



Childhood sex-typed behaviour



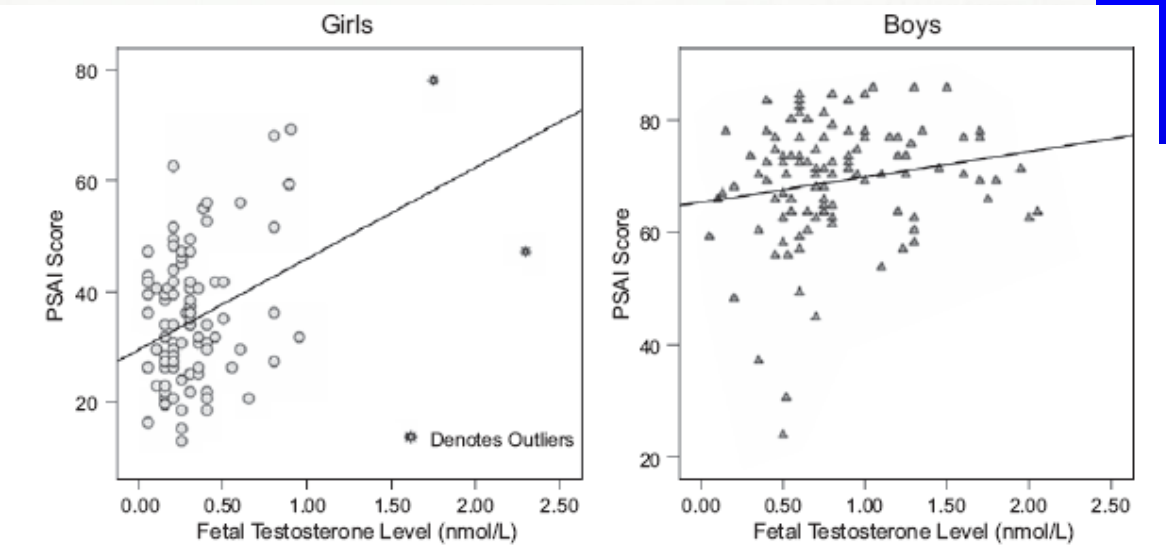


Fig. 1. Scatter plot showing the relation between Pre-School Activities Inventory (PSAI) score and fetal testosterone level, among girls (left) and boys (right).

Auyeung et al. (2009)

Final Hierarchical Regression Models for the Pre-School Activities Inventory

Group and predictor	R^2	β	*SE*	*p*
Boys and girls combined	.73			
Fetal testosterone level		.14	2.28	<.01
Sex		.77	1.94	<.001
Girls	.11			
Fetal testosterone level		.27	4.17	<.05
Maternal age		.18	0.09	>.05
Boys	.04			
Fetal testosterone level		.21	2.66	<.05
Maternal age		.20	0.12	<.05

Fetal testosterone and activity preferences

Auyeung et al. 2009 *Psych. Sci.*

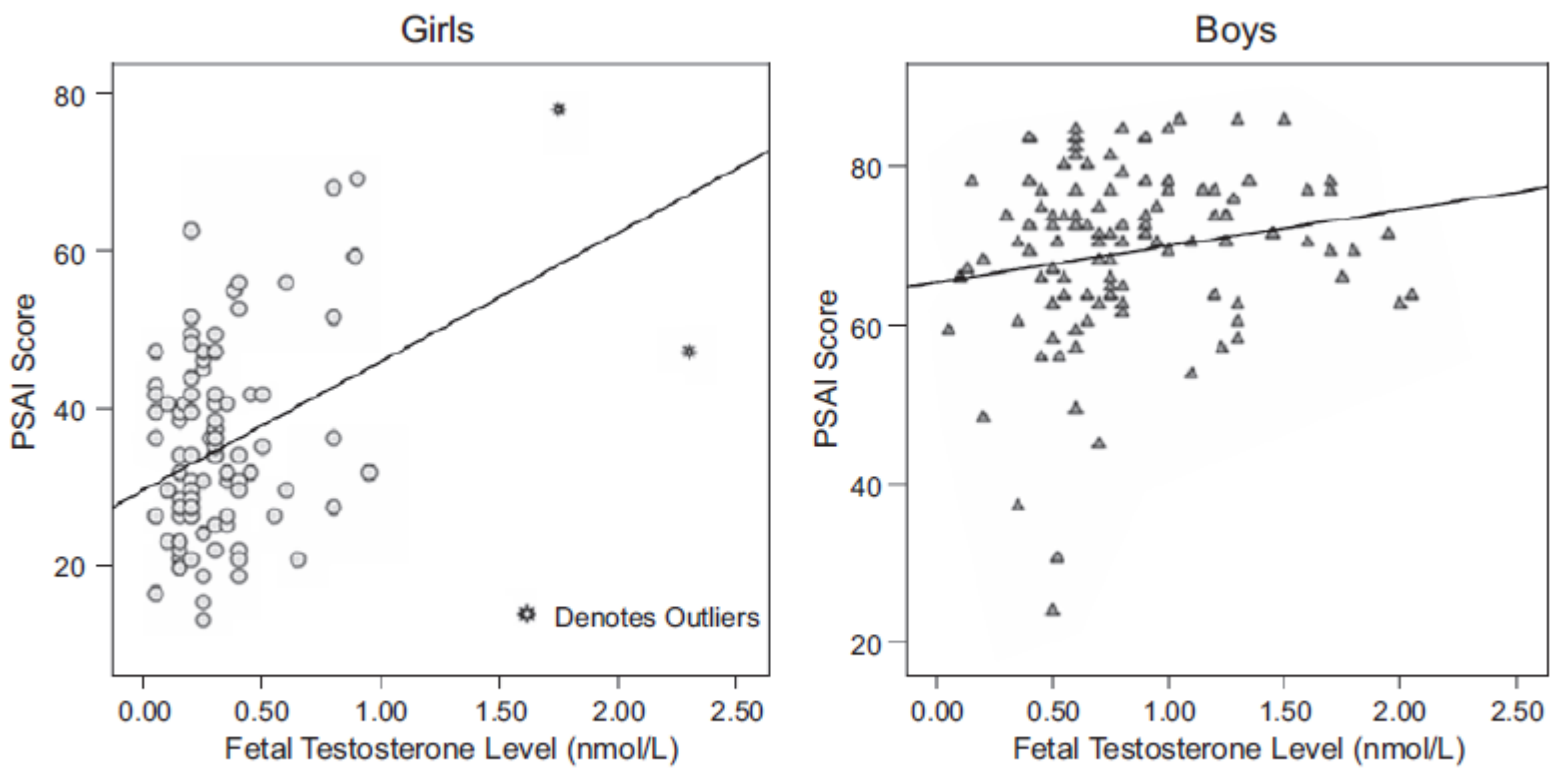
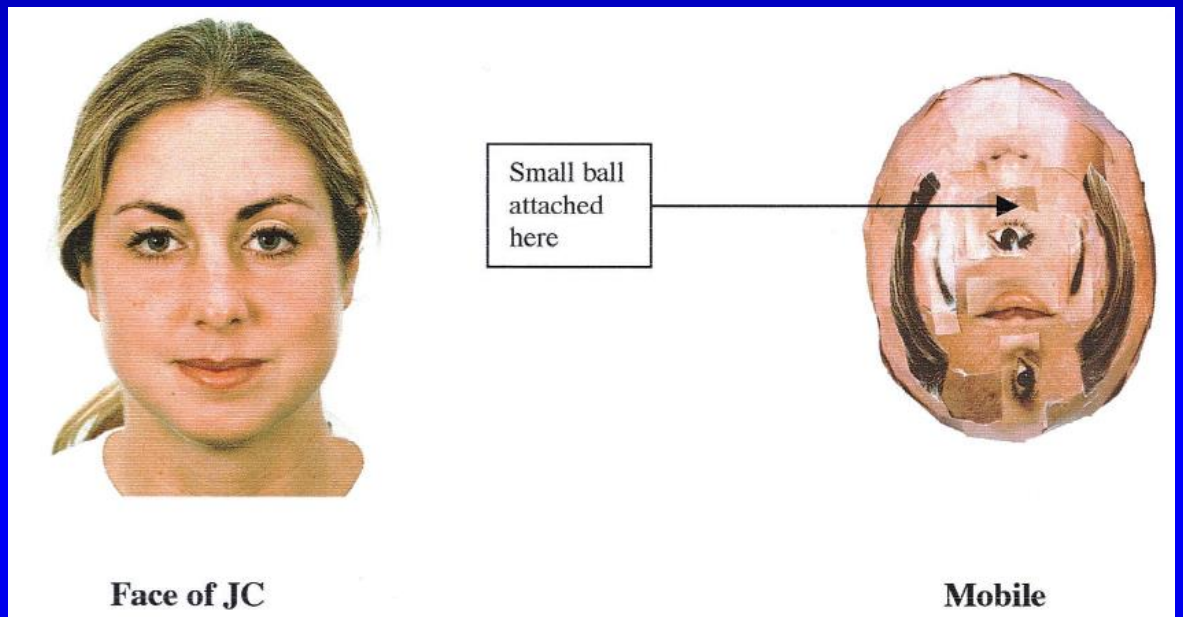


Fig. 1. Scatter plot showing the relation between Pre-School Activities Inventory (PSAI) score and fetal testosterone level, among girls (left) and boys (right).

Evidence for sex-typed preferences from birth (Connellan et al. 2000)



- Egalement à 12 mois: Lutchmaya & Baron-Cohen 2002

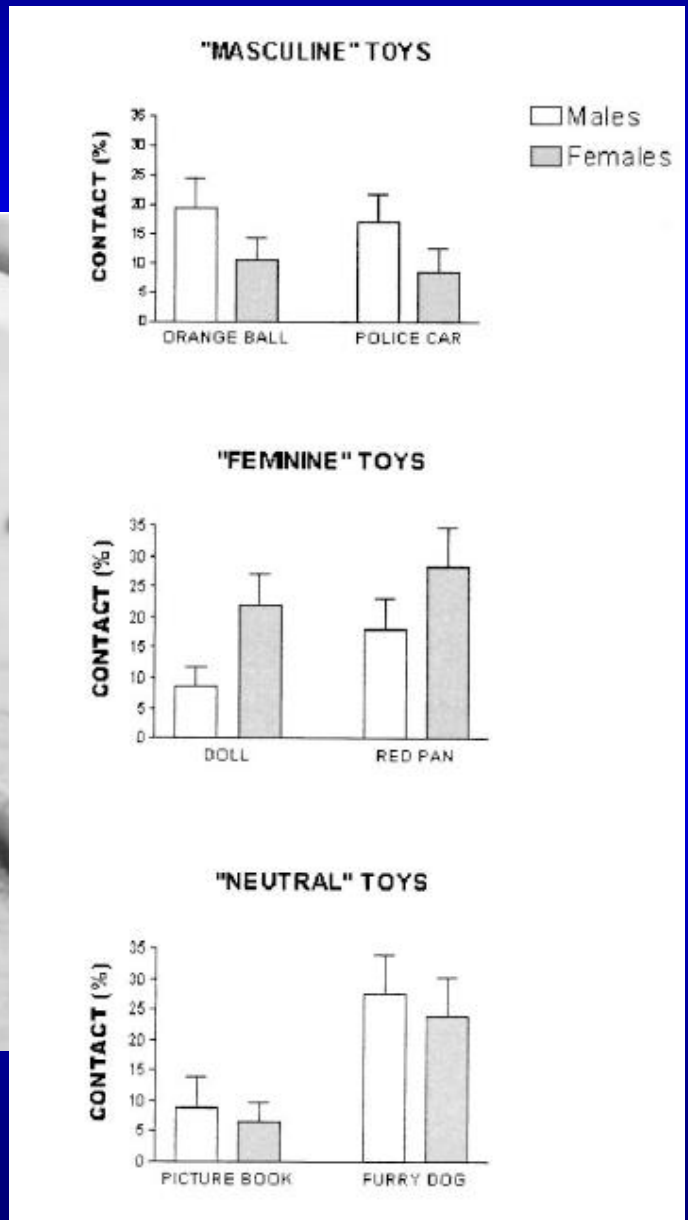
Number (and percent) of neonates falling into each perference category

	Face Preference	Mobile Preference	No Preference
Males (n = 44)	11 (25.0%)	19 (43.2%)	14 (31.8%)
Females (n = 58)	21 (36.2%)	10 (17.2%)	27 (46.6%)

Mean percent looking times (and standard deviation) for each stimulus

	Face	Mobile
Males (n = 44)	45.6 (23.5)	51.9 (23.3)
Females (n = 58)	49.4 (20.8)	40.6 (25.0)

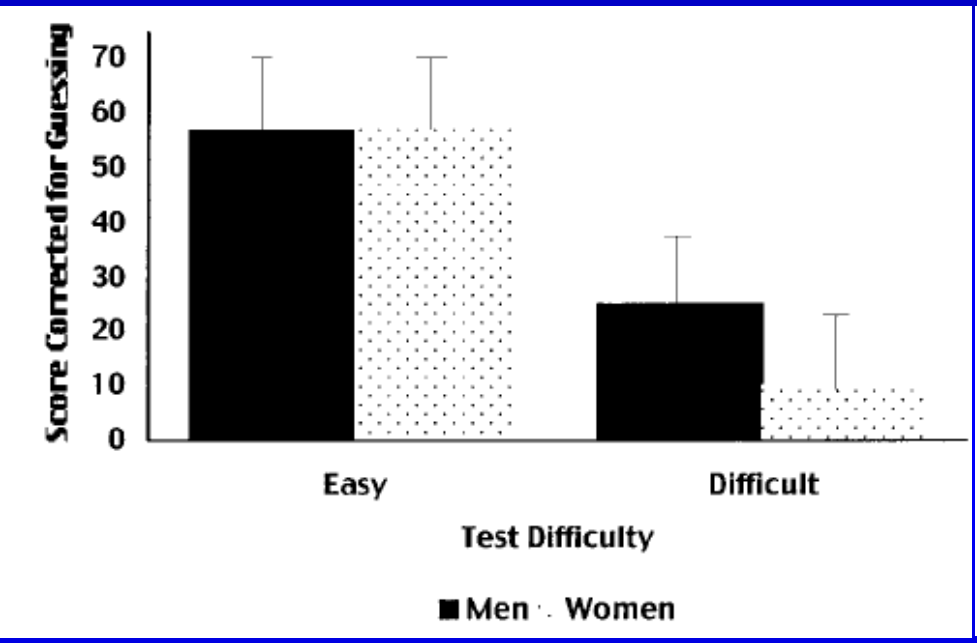
Even in non-human primates… Alexander & Hines 2002

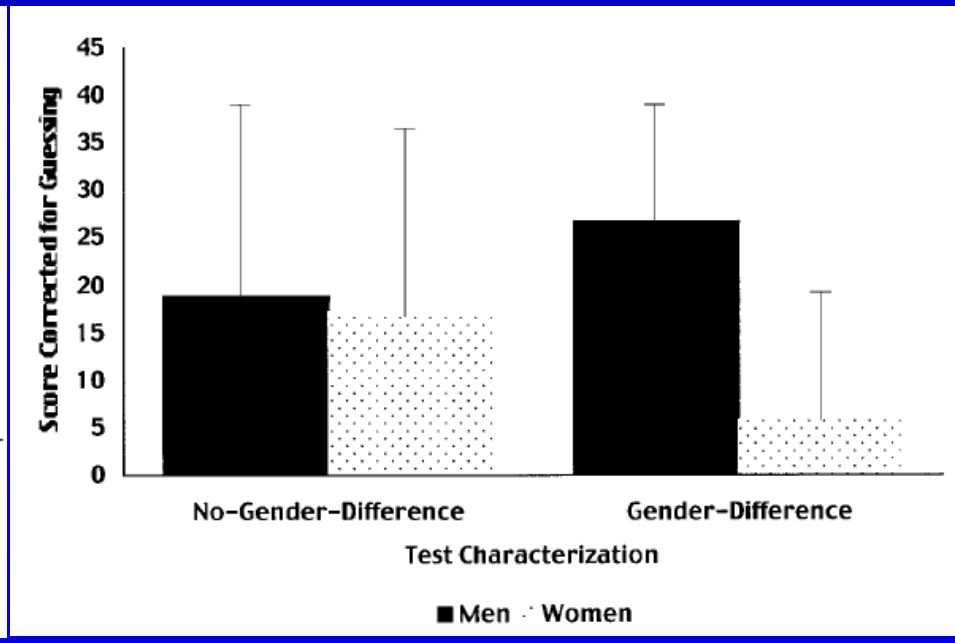


•Répliqué par Hassett et al. 2008 *Horm. Behav.*

Stereotype threat: Gender-biasing contexts

Spencer, Steele & Quinn 1999

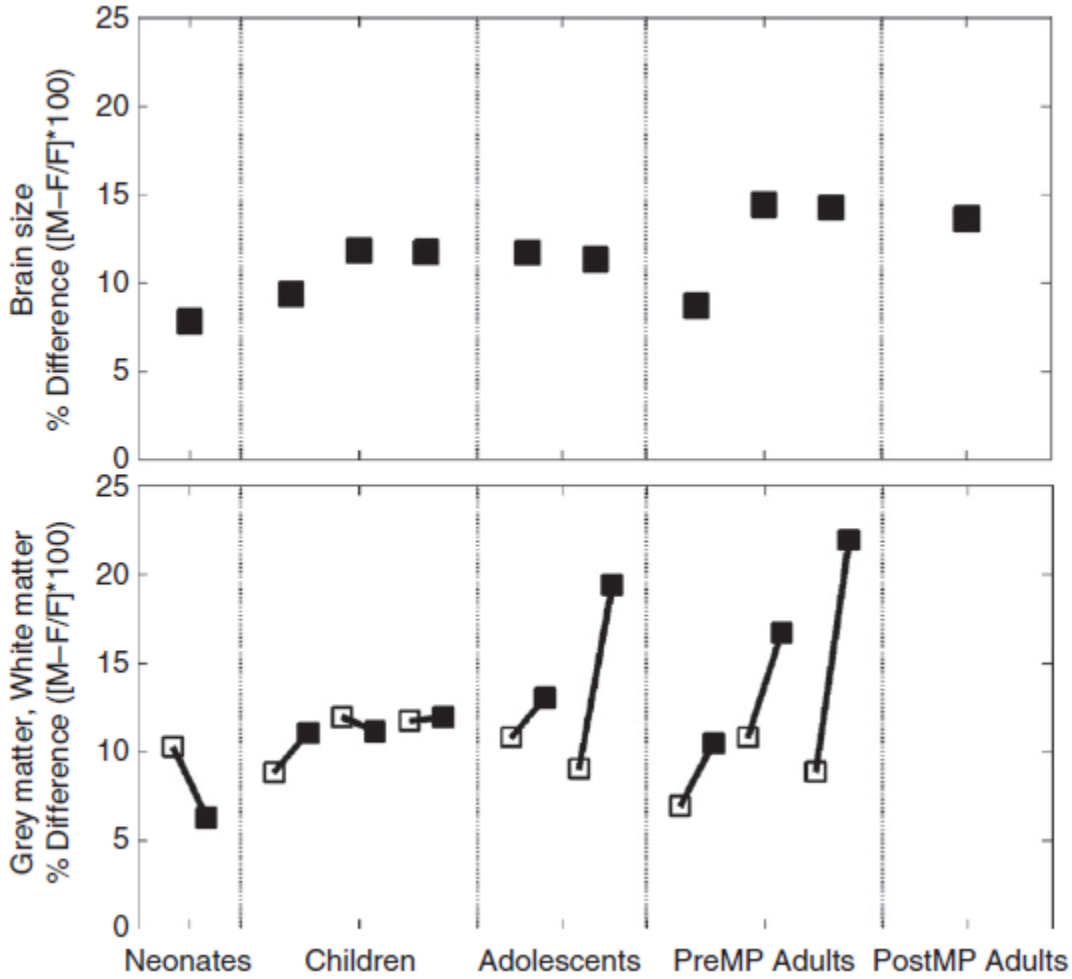




- Effect size: 0.26 (Nguyen & Ryan 2008, *J. Applied Psych.*)

Gray and white matter volume differences even at birth

(Paus et al. 2010)



Brain volume differences at birth, with weight controlled

Gilmore et al. 2007 *J. Neurosci.*

Table 1. Sexual dimorphism

	Male, mean (SD)	Female, mean (SD)	Difference, M > F (%)	*p* value
Birth weight (g)	3587.7 (465.5)	3278.7 (407.7)	9.42	0.0036
ICV (mm^3)	525,524 (58,637)	487,378 (41,848)	7.83	0.0023
Hem GM (mm^3)	218,212 (28,693)	197,945 (197,944)	10.24	0.0012
Hem umWM (m^3)	163,987 (18,420)	154,146 (15,745)	6.38	0.0169
Subcort GM (mm^3)	24,390 (4229)	22,628 (2823)	7.79	0.0423
Lat ventricle (mm^3)	2927 (2054)	2771 (3944)	5.67	0.8277
Cerebellum (mm^3)	28,227 (4050)	26,893 (3156)	4.96	0.1235

Hem, Hemispheric; Subcort, subcortical; GM, gray matter; umWM, unmyelinated white matter; Lat; lateral; M, male; F, female; NA, not applicable.

- Males had significantly larger ICVs compared with females, even controlling for birth weight ($F(1,71)=4.3$; $p=0.0418$).

Sex differences in the volumes of specific structures

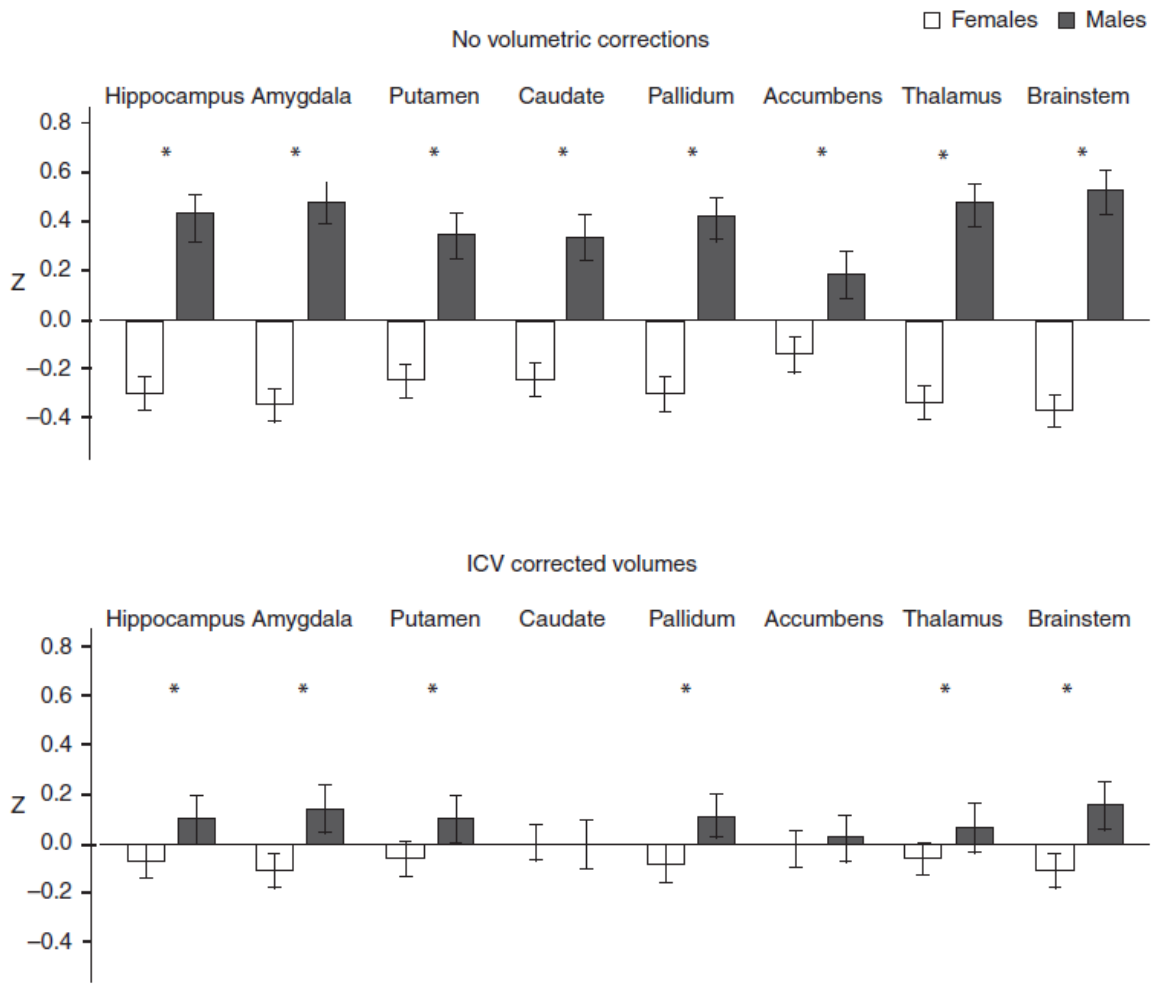
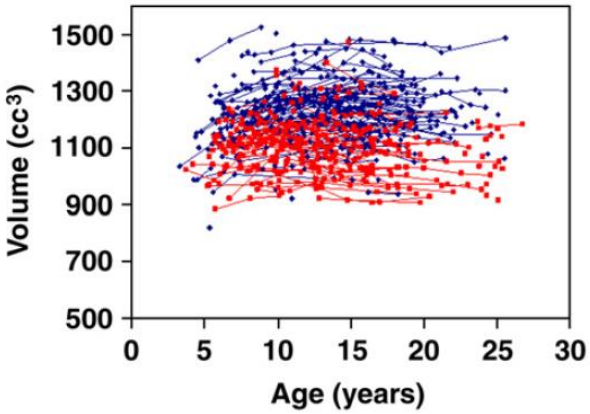


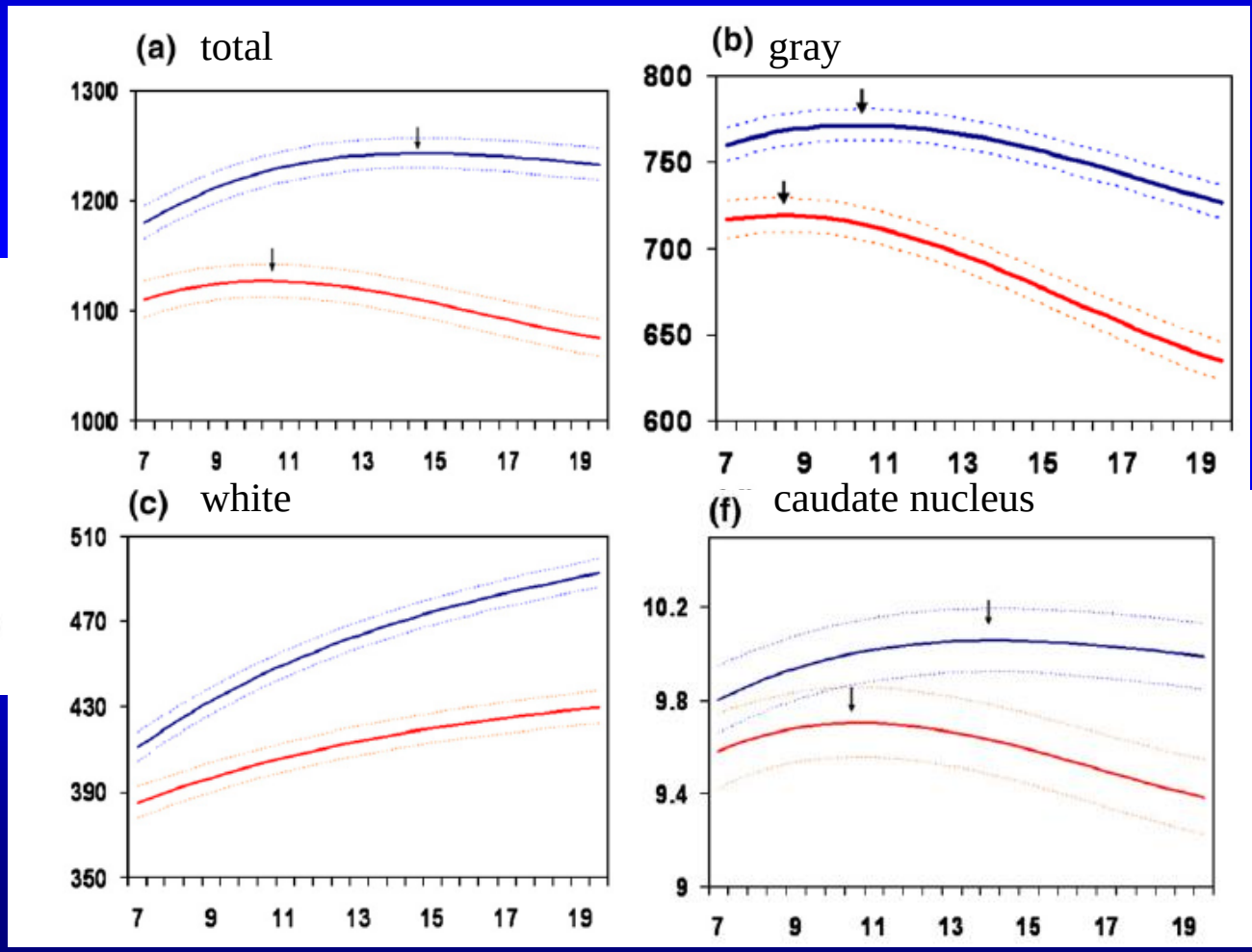
Fig. 4. Sex differences in regional brain volumes: adults. **Top row**: Sex differences in the absolute volume of eight brain structures as estimated by Freesurfer in a sample of adults ($n = 1143$; Fjell et al., 2009). **Bottom row**: Sex differences in the volumes of the same structures after adjustment for the intracranial volume. ICV, intracranial volume. Reprinted with permission from Fjell et al. (2009).

Sexual dimorphism of brain developmental trajectories during childhood and adolescence☆

Rhoshel K. Lenroot,[a,*] Nitin Gogtay,[a] Deanna K. Greenstein,[a] Elizabeth Molloy Wells
Gregory L. Wallace,[a] Liv S. Clasen,[a] Jonathan D. Blumenthal,[a] Jason Lerch,[b]
Alex P. Zijdenbos,[c] Alan C. Evans,[c] Paul M. Thompson,[d] and Jay N. Giedd[a]

NeuroImage

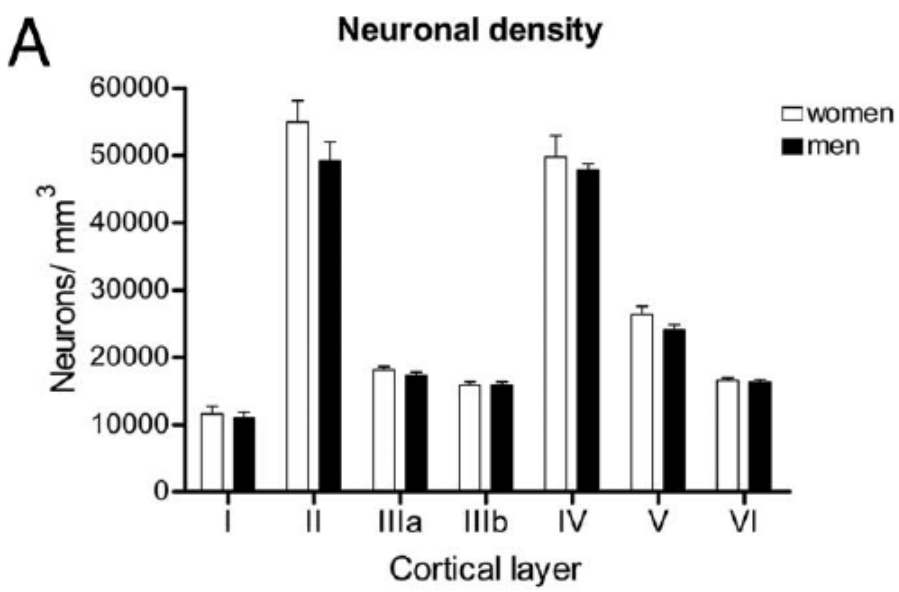


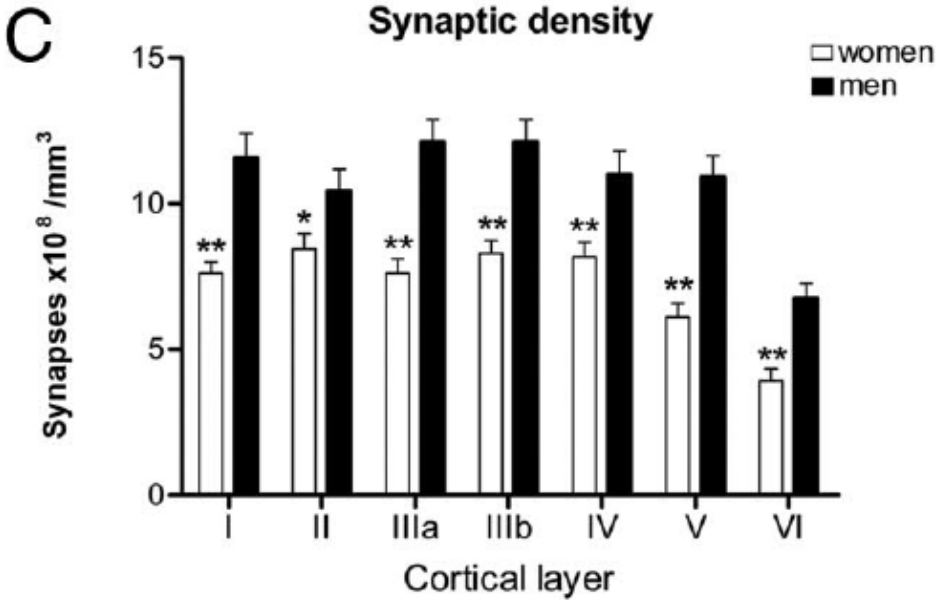


Gender differences in human cortical synaptic density

L. Alonso-Nanclares*†, J. Gonzalez-Soriano‡, J. R. Rodriguez*, and J. DeFelipe*

PNAS | September 23, 2008 | vol. 105 | no. 38 | 14615–14619





- Only temporal cortex analysed; 4 M / 4 F.
- No difference in cytoarchitecture (cortical thickness, proportion of neuropil/cells/blood vessels…)

Summary on sex differences

- No sex difference in global IQ
- But reliable sex differences in many cognitive traits.
  - Some in favour of males, some in favour of females
  - Effect sizes: 0.2 – 1.
- All of these differences may be to some extent influenced by environmental/social factors.
- Stereotype threat affects female performances, but cannot explain all differences.
- Some of these differences (mental rotation, toy/activity preferences, aggressivity) can also be observed:
  - In young infants
  - In non-human species
  - Intermediate in CAH female individual
- Differences in brain structure
  - Brain volume (even at birth, even accounting for differences in body size)
  - Volume and characteristics of many different structures, even accounting for total brain volume.
- Links between cognitive and brain differences unclear.