The fragile biology of social genes and the evolution of human societies

Professor Keith Kendrick

Babraham Institute

What is social behaviour?

Mutually beneficial interactions among individuals within the same species

Evolved because it promoted 'survive and reproduce'

What is social behaviour?

Sociability in female baboons promotes infant survival

Silk *et al* 2003

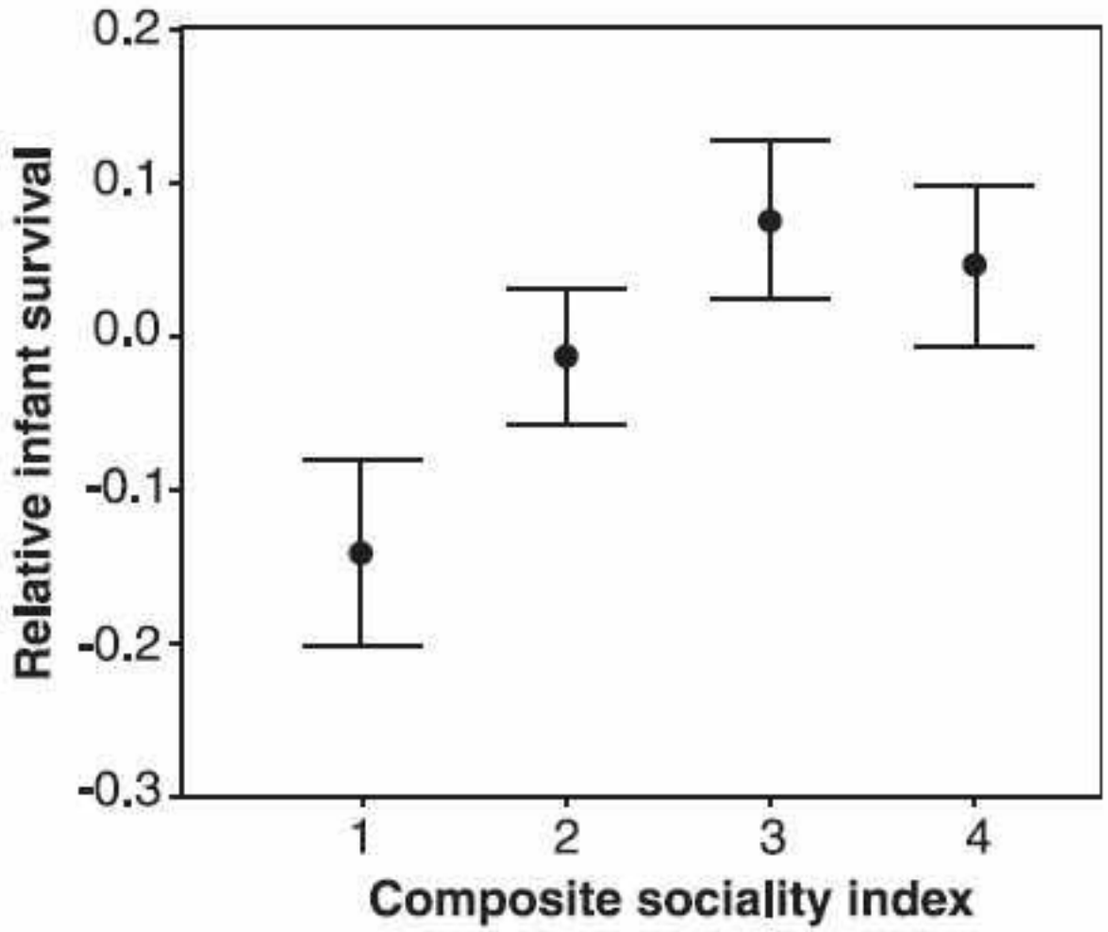


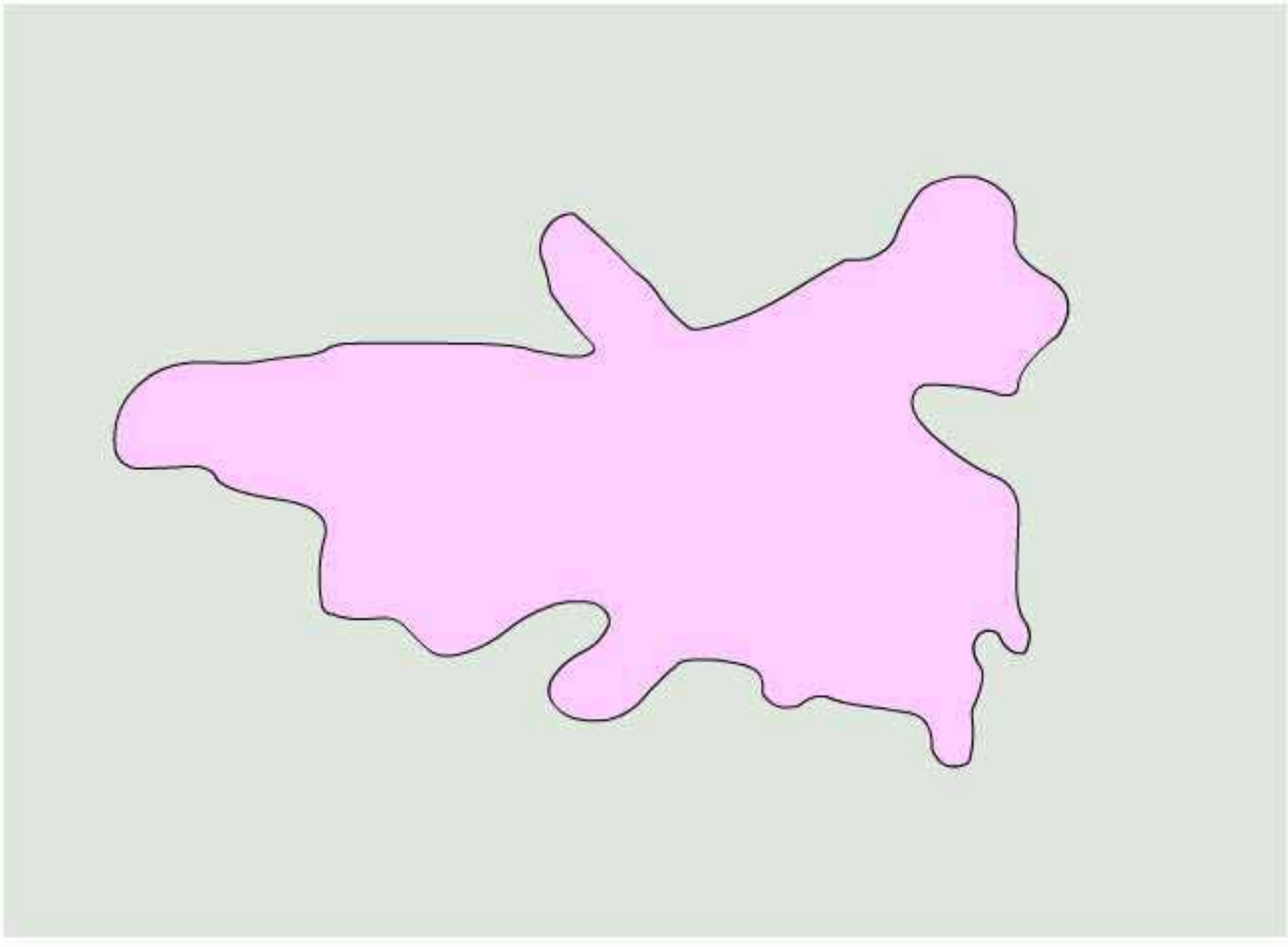
Fig. 1. Effects of sociality on infant survival.

What is social behaviour?

Can be seen in species from amoeba...

What is social behaviour?

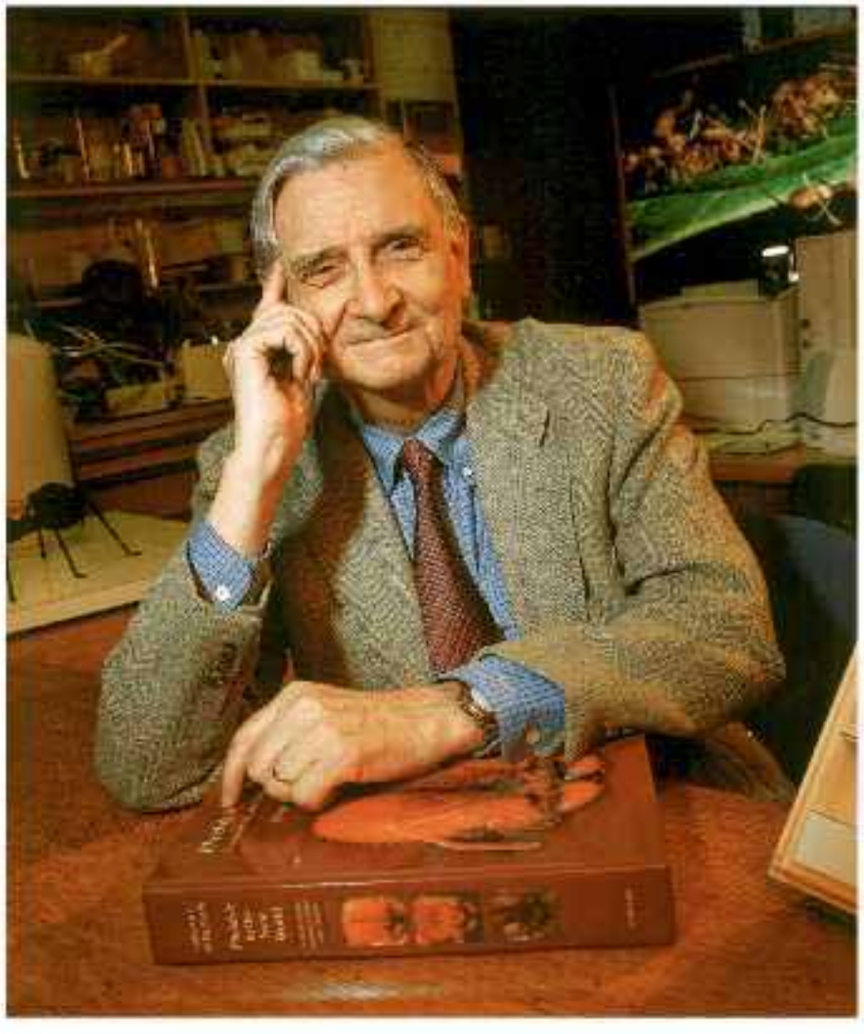
Can be seen in species from amoeba...
...through to humans



What is social behaviour?

Can be seen in species from amoeba through to humans

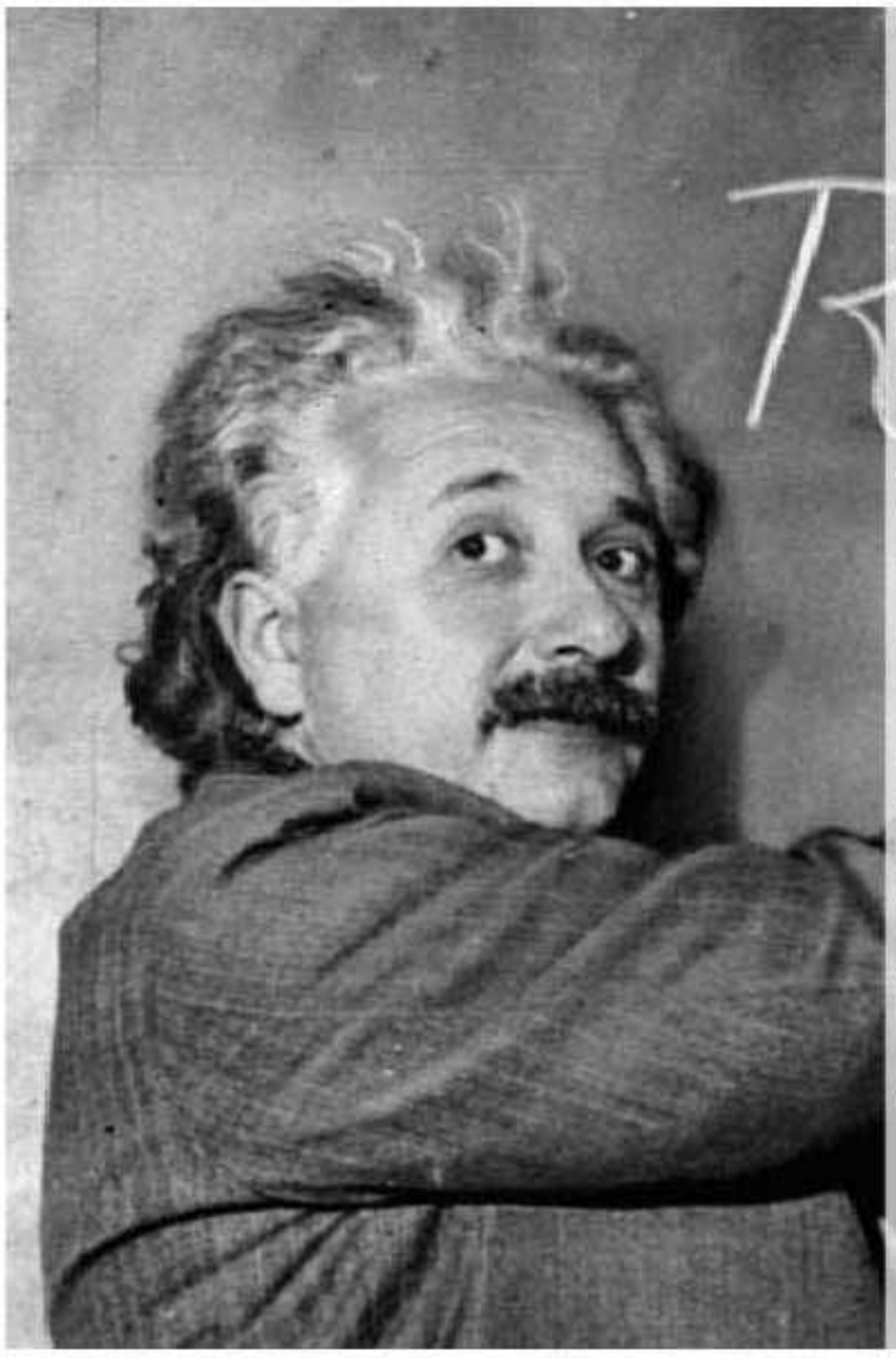
Must have strong genetic basis hence 'Sociobiology'



Many find this hard to square with 'free-will'

Edward O Wilson

The continuing nature vs. nurture debate



'...it is quite possible that the relative strength of these two drives is, in the main, fixed by inheritance. But the personality that finally emerges is largely formed by the environment in which a man happens to find himself during his development, by the structure of the society in which he grows up, by the tradition of that society, and by its appraisal of particular types of behavior'

Albert Einstein: Why Socialism? - Monthly Review May 1949

What are the advantages of being social?

Co-operation and altruism have a price

What are the advantages of being social?

Parental behaviour - nurturing offspring at cost to oneself!

What are the advantages of being social?

Sometimes even males get involved

What are the advantages of being social?

Eusocial insects - 'queens' and 'workers'

What are the advantages of being social?

Eusocial mammals

The naked mole rat *(Heterocephalus glaber)*

What are the advantages of being social?

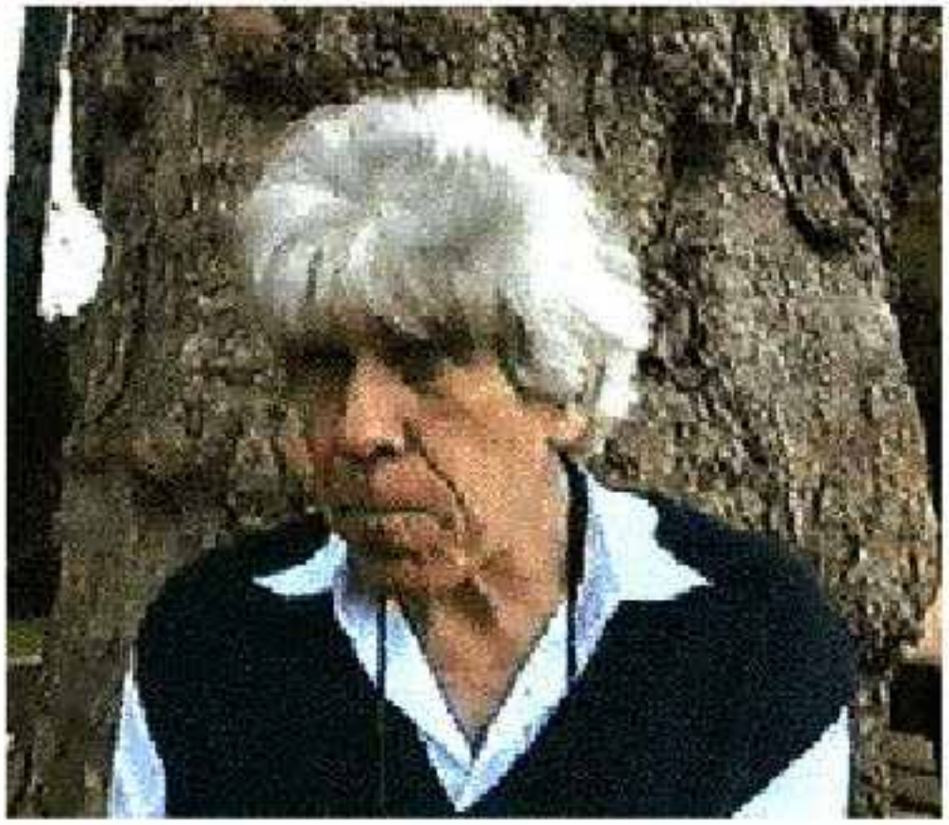
Eusocial mammals

The naked mole rat *(Heterocephalus glaber)*

The Damaraland mole rat *(Cryptomys damarensis)*

So what might lead to these behaviours?

Selfish genes can lead to co-operation and altruism
– kin selection

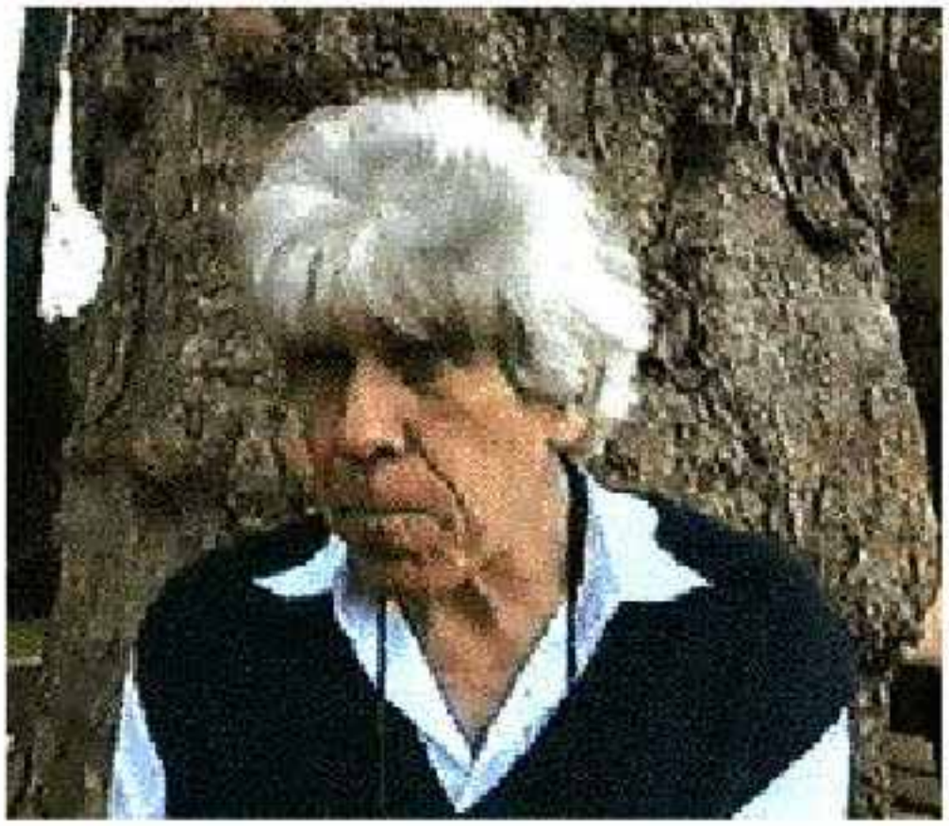


WD Hamilton

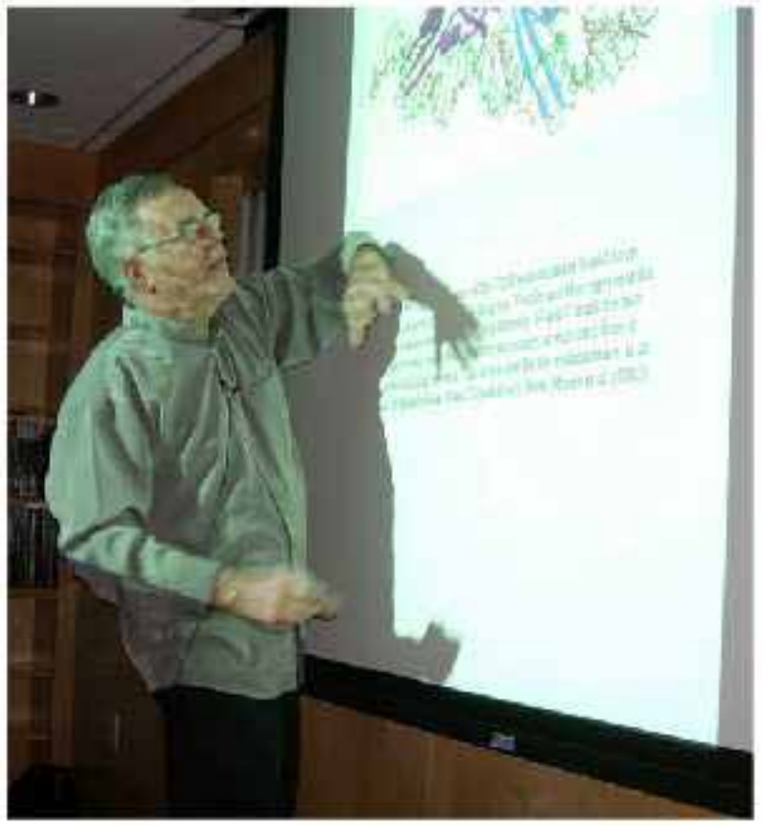
So what might lead to these behaviours?

Selfish genes can lead to co-operation and altruism – kin selection

Social co-operation in many species extends beyond kin



WD Hamilton

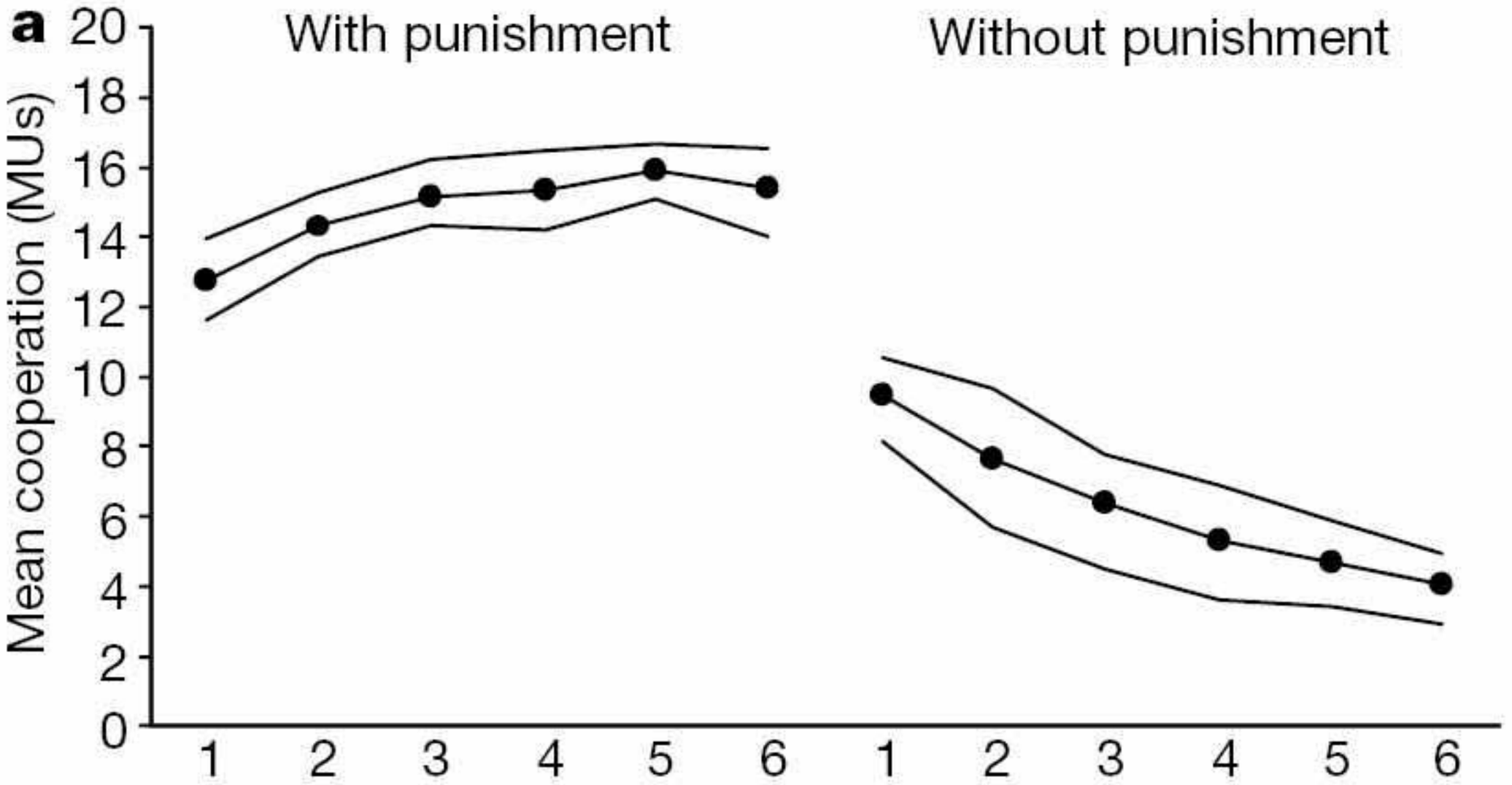


Robert Trivers

So what might lead to these behaviours?

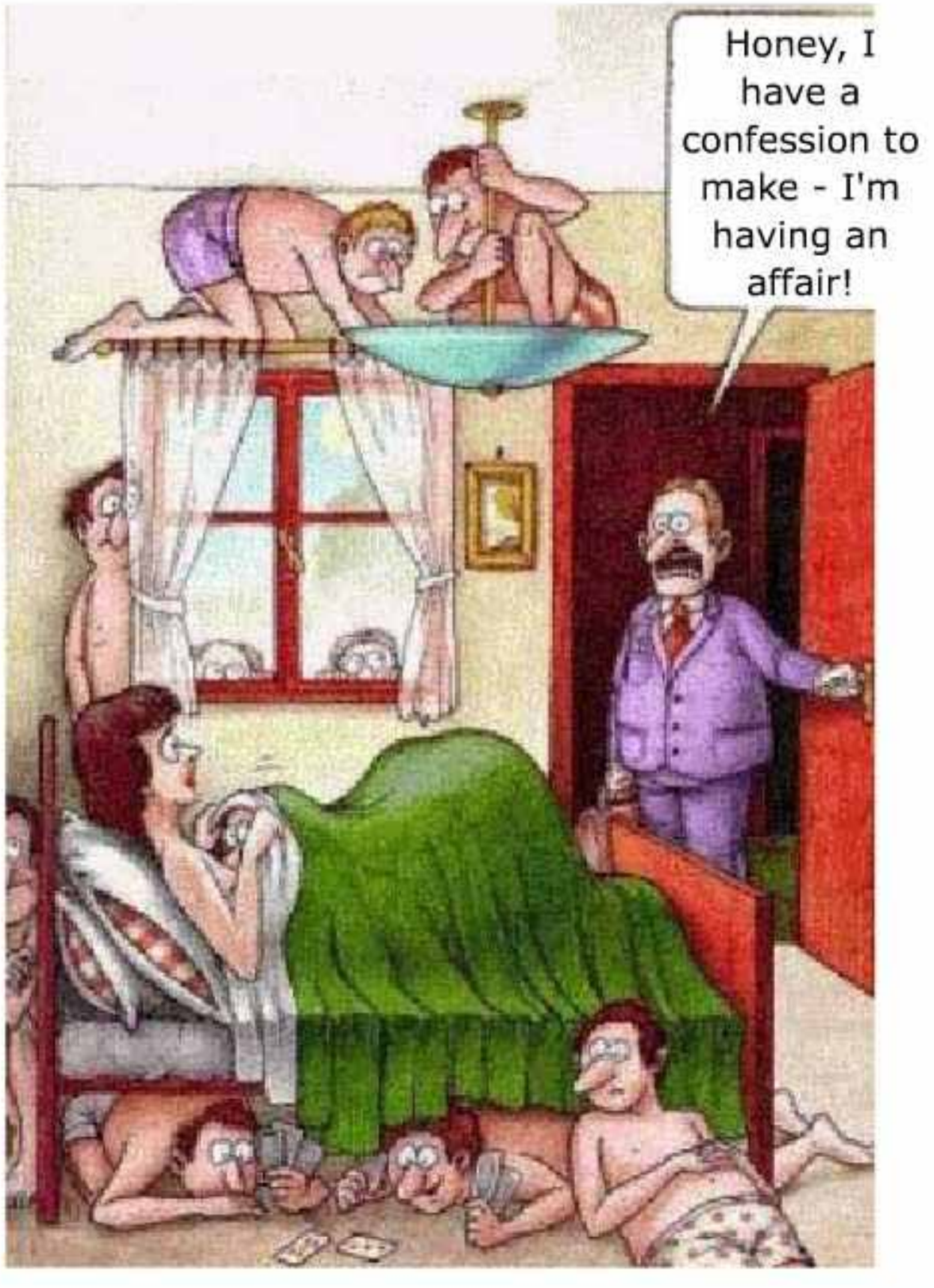
'Altruistic punishment' of non-cooperators

Ernst Fehr and Simon Gächter 2002



So what might lead to these behaviours?

There must be significant costs associated with cheating!



Social genes

Solitary vs. social across species

Social genes

Solitary vs. social across species

Solitary vs. social within the same species

Social genes

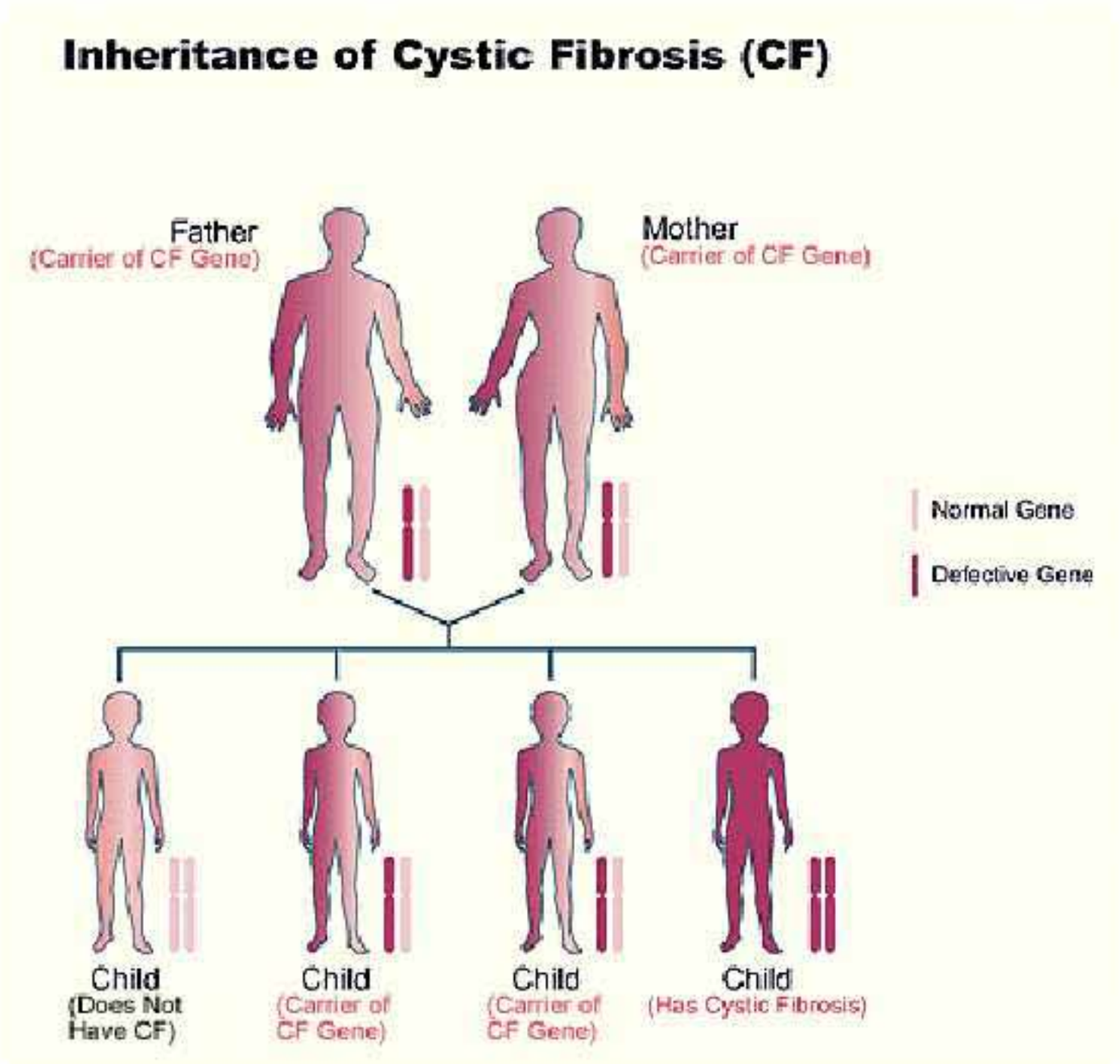
Solitary vs. social across species

Solitary vs. social within the same species

Often a single gene polymorphism or deletion alters social behaviour

Hard and soft inheritance

Hard inheritance: Nucleotide based genes inherited bi-allelically



Hard and soft inheritance

Hard inheritance: Nucleotide based genes inherited bi-allelically

Inheritance of acquired traits?

Jean-Baptiste Lamarck (1744 - 1829)

Hard and soft inheritance

Hard inheritance: Nucleotide based genes inherited bi-allelically

Inheritance of acquired traits?

Jean-Baptiste Lamarck (1744 - 1829)

Hard and soft inheritance

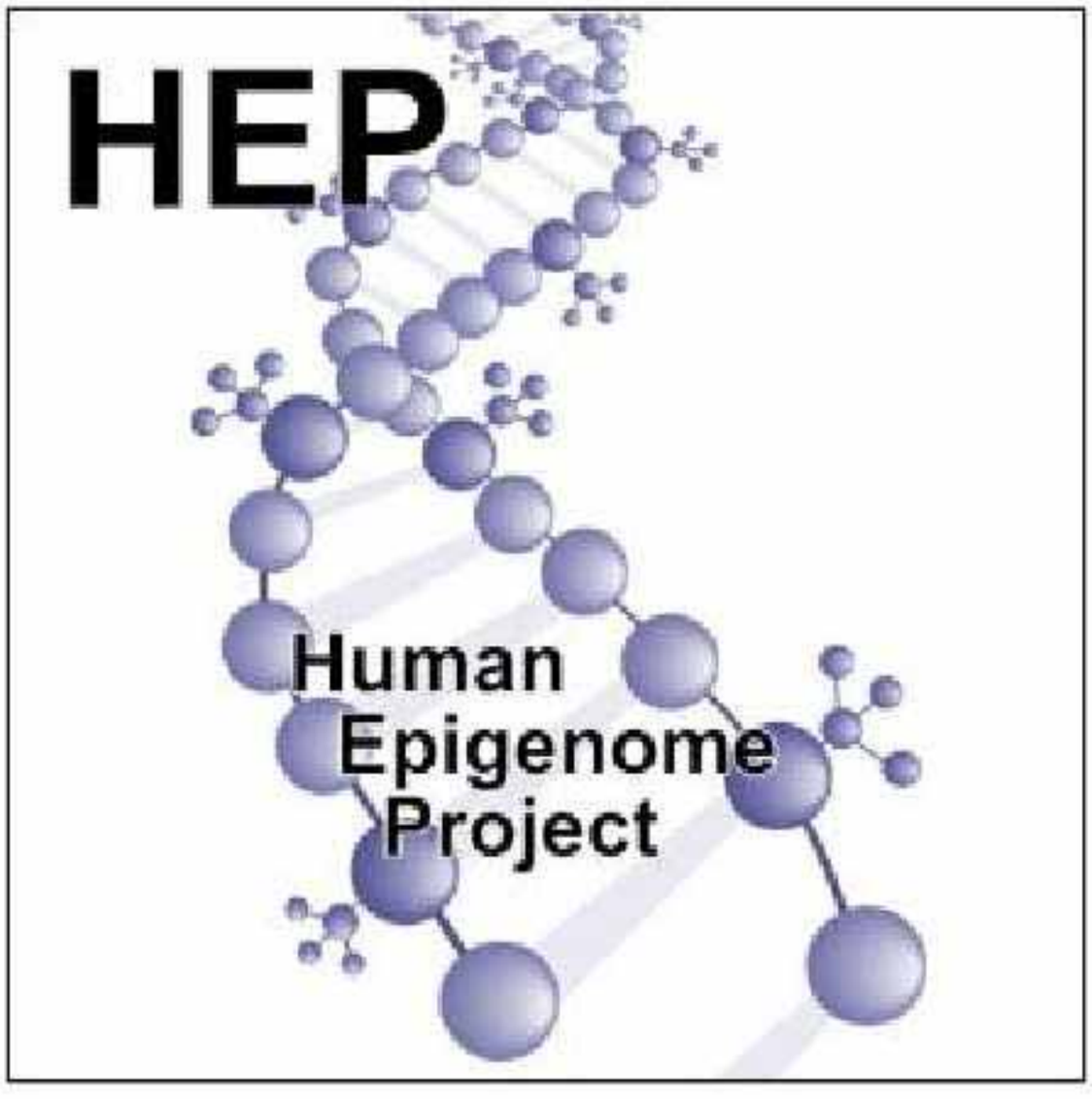
Hard inheritance: Nucleotide based genes inherited bi-allelically

Inheritance of acquired traits?

Trofim Denisovitch Lysenko
(1898 - 1976)

Hard and soft inheritance

Soft inheritance: the epigenome and epigenetics

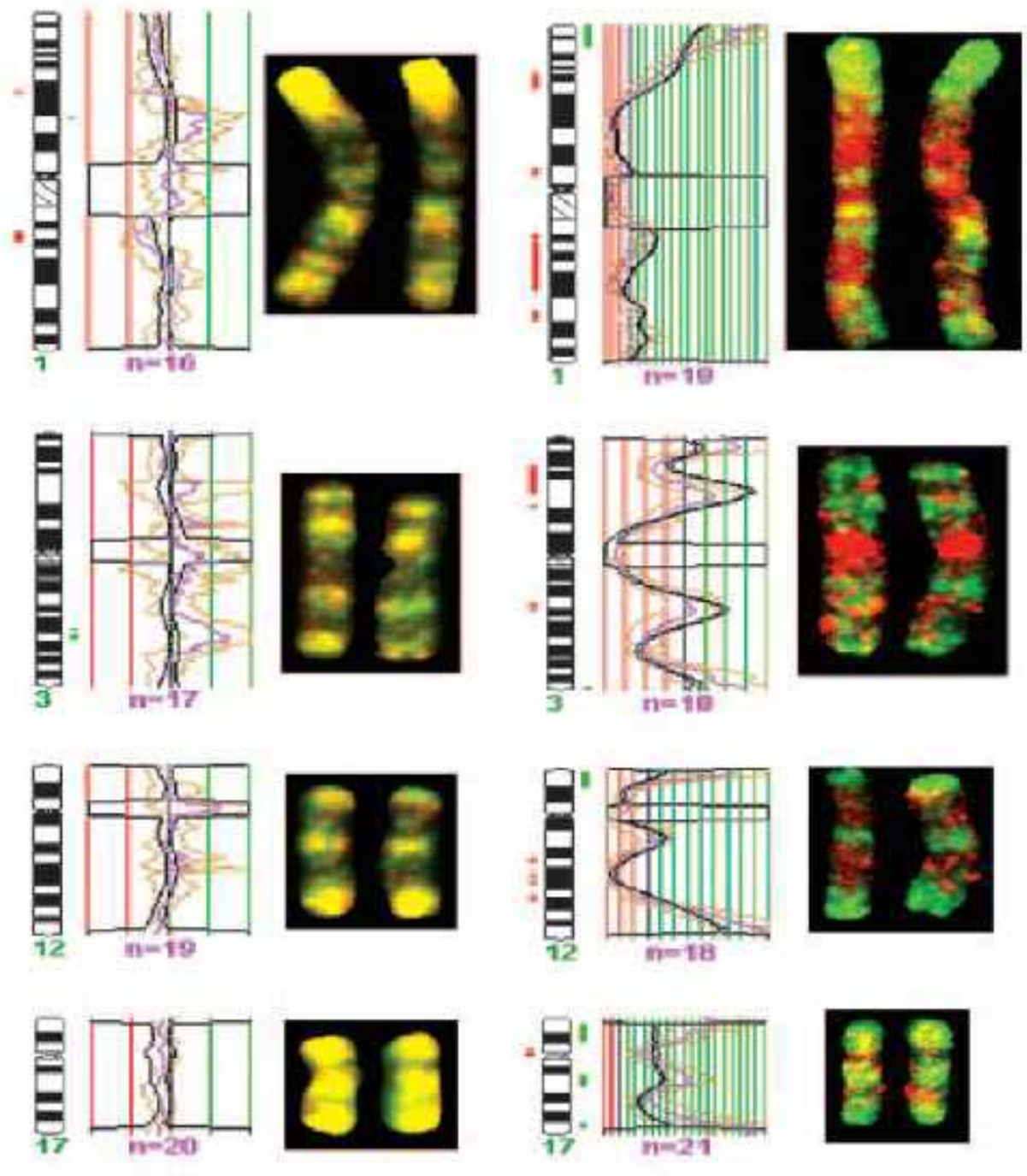


Extra layer of modification instructions passed down from parent to child

Hard and soft inheritance

Epigenetic marks - methylation changes and histone modifications

These modifications are not usually passed on to the next generation



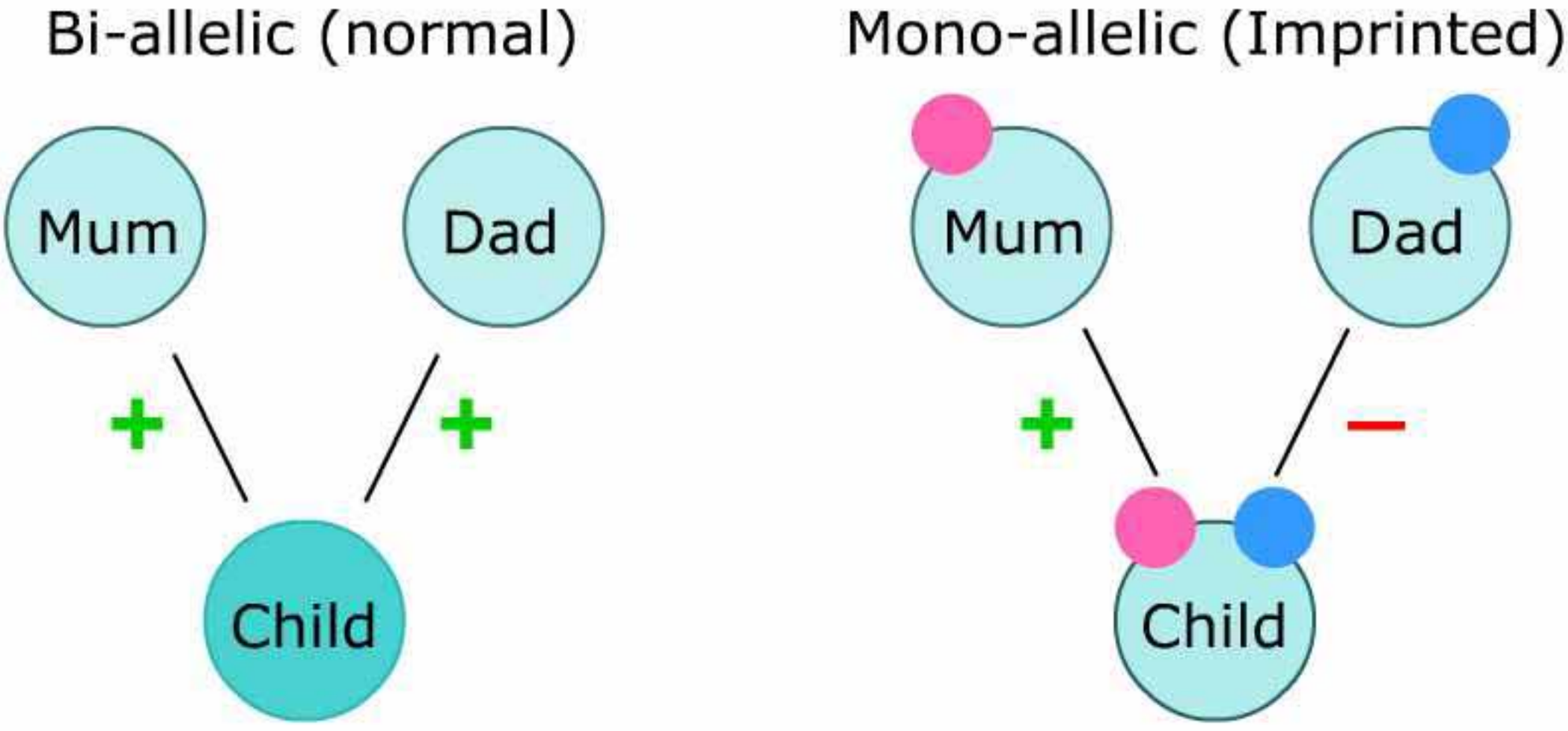
Fraga *et al* 2005

Hard and soft inheritance

However there are increasing examples where they are

Hard and soft inheritance

Epigenetics and imprinted genes



Hard and soft inheritance

Epigenetics and imprinted genes

There are only 100 imprinted genes but they may be important for social behaviour

Identifying social genes

Prosocial genes account for 40% similarity in monozygotic twins

Rushton 2005

THE ROYAL SOCIETY

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Genetic and environmental contributions to pro-social attitudes: a twin study of social responsibility

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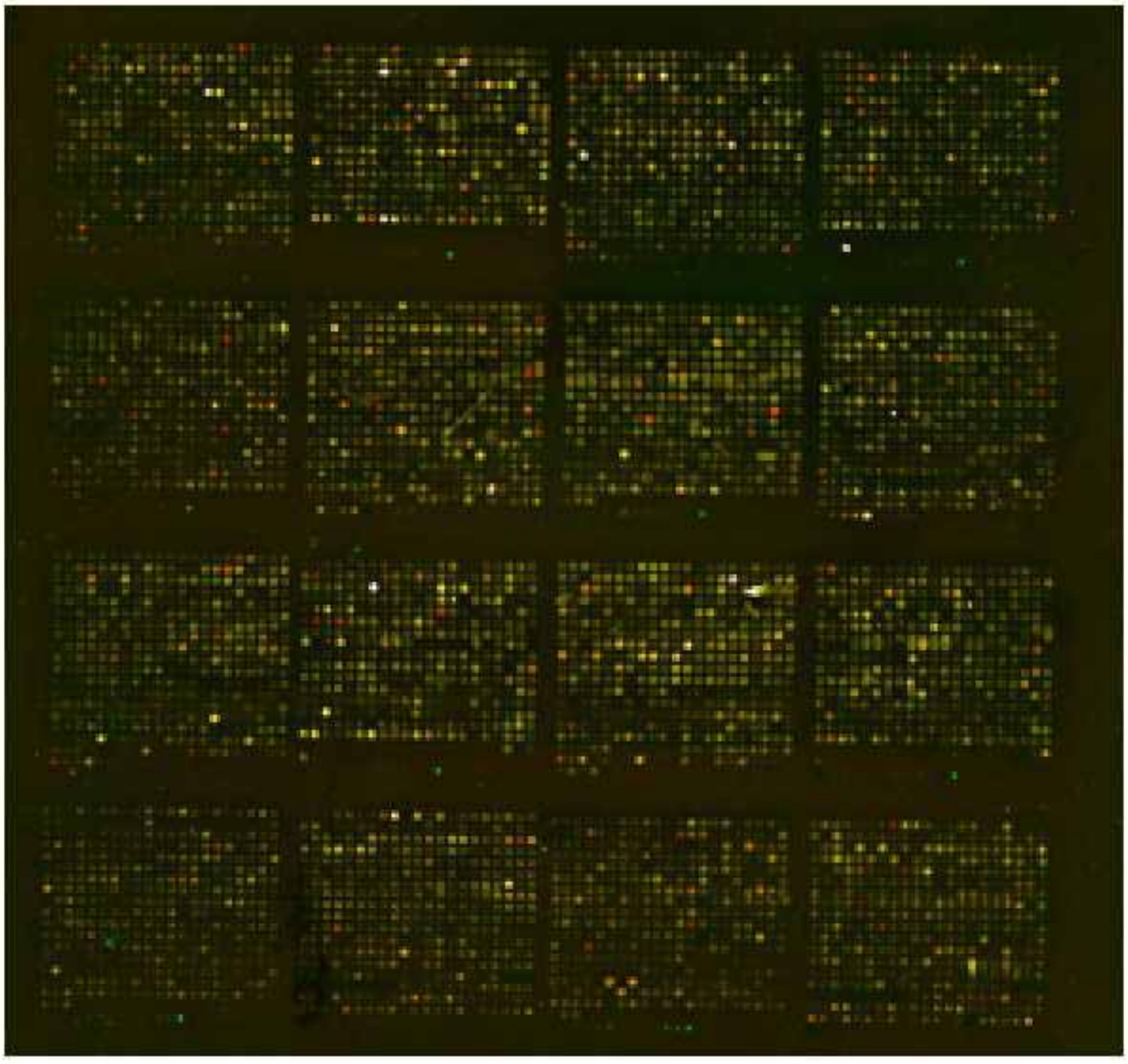
23% is due to shared environment

Identifying social genes

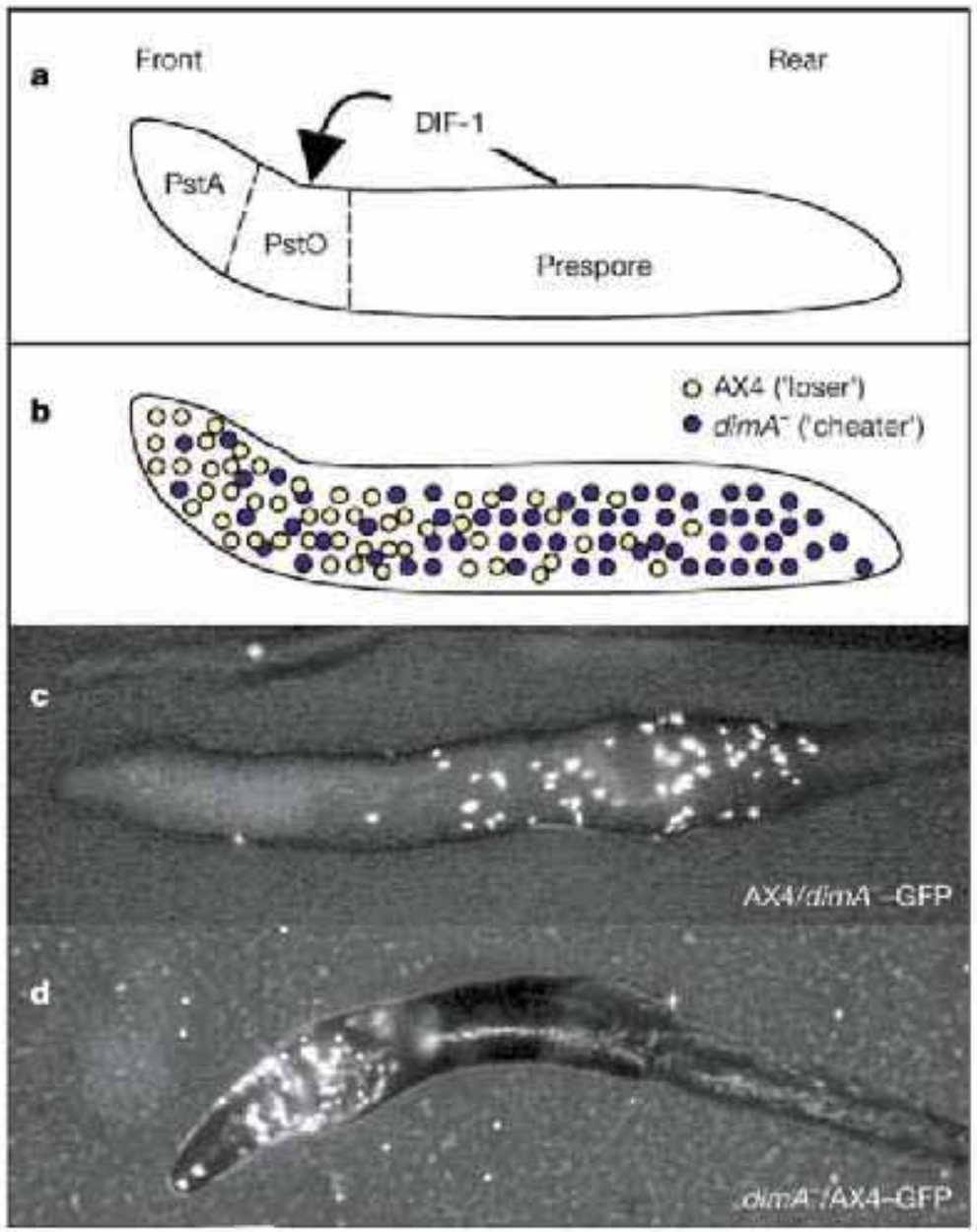
Gene screening experiments are underway

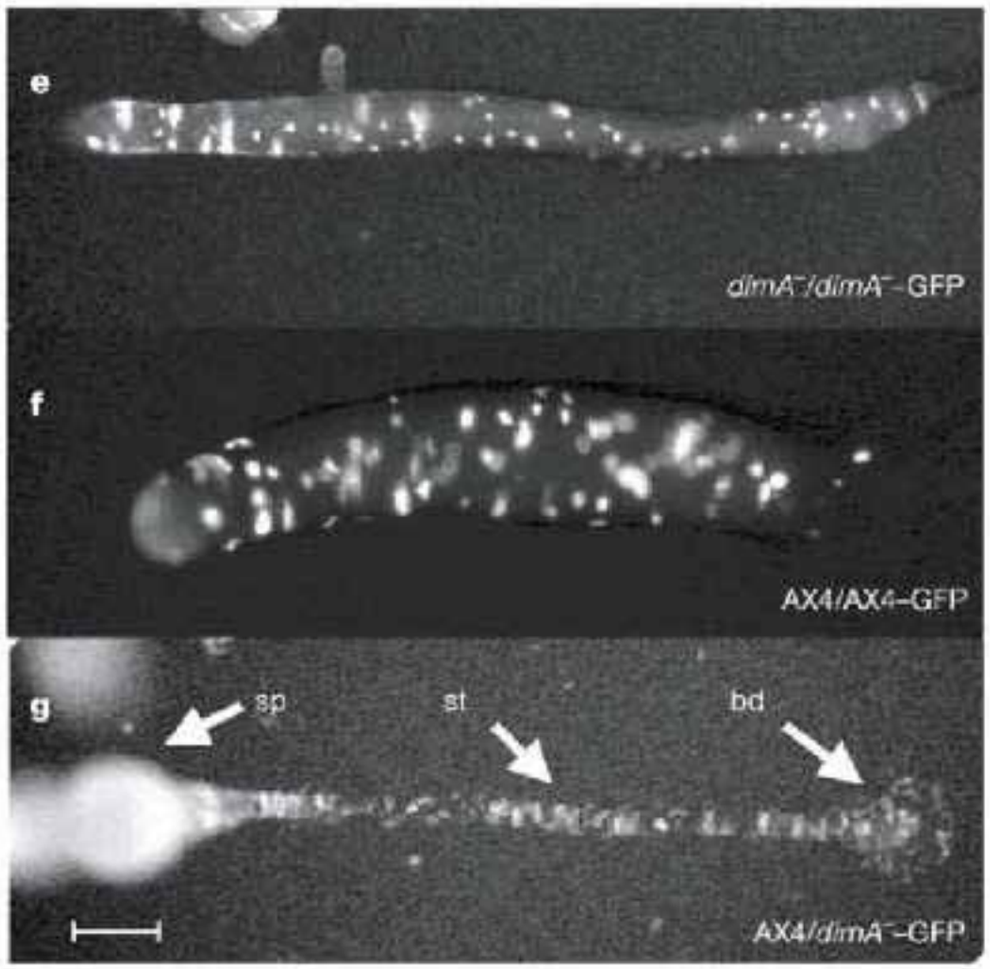


Effects of gene deletions and polymorphisms

Cell signalling gene ***DIF-1*** in amoeba is linked to cooperative behaviour

Foster *et al* 2004

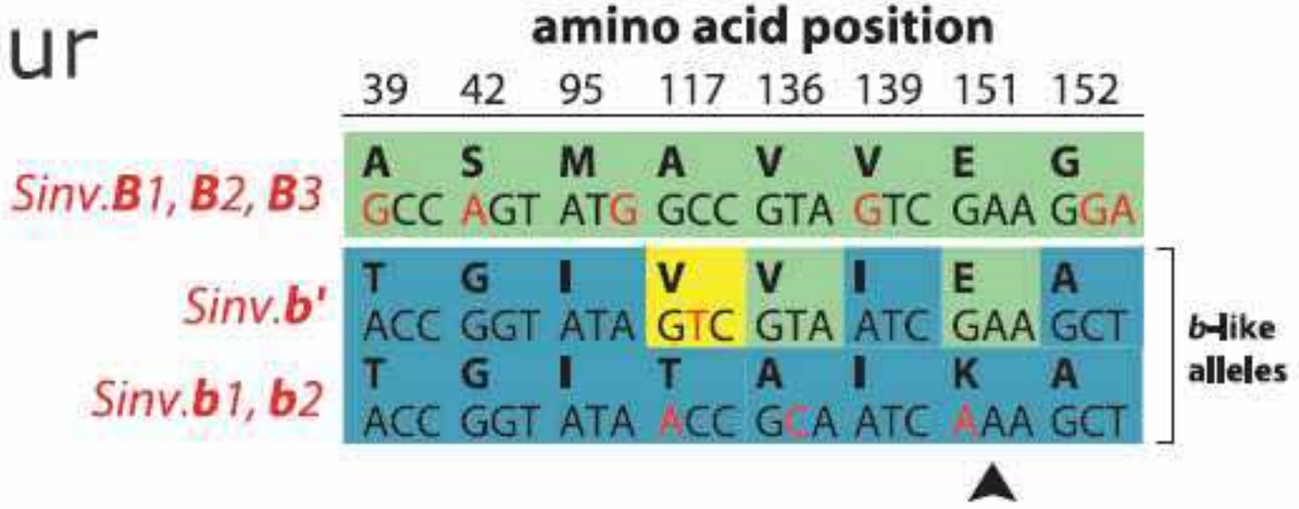


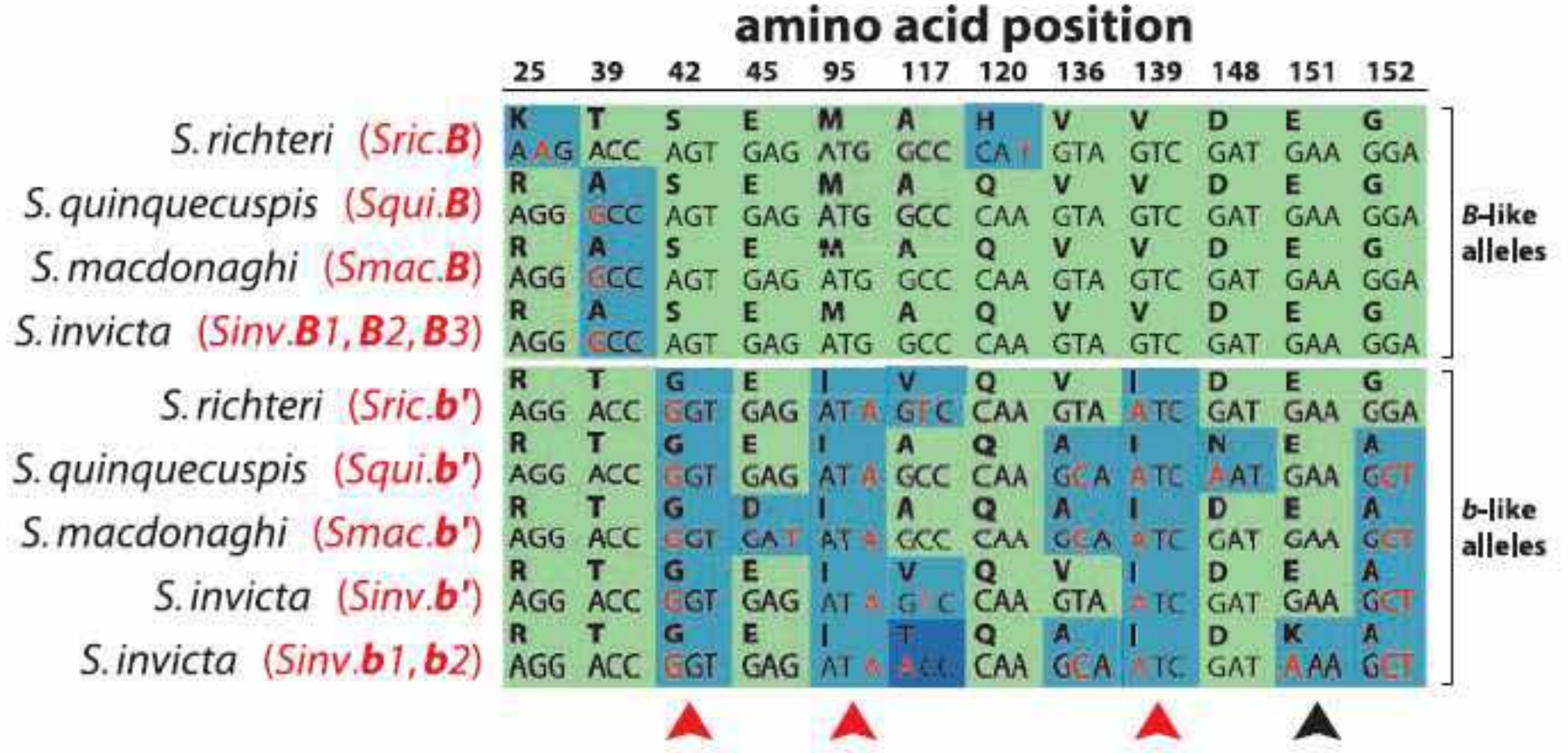


Effects of gene deletions and polymorphisms

In fire ants ***Gp-9*** gene polymorphism controls worker social behaviour

Krieger and Ross 2002

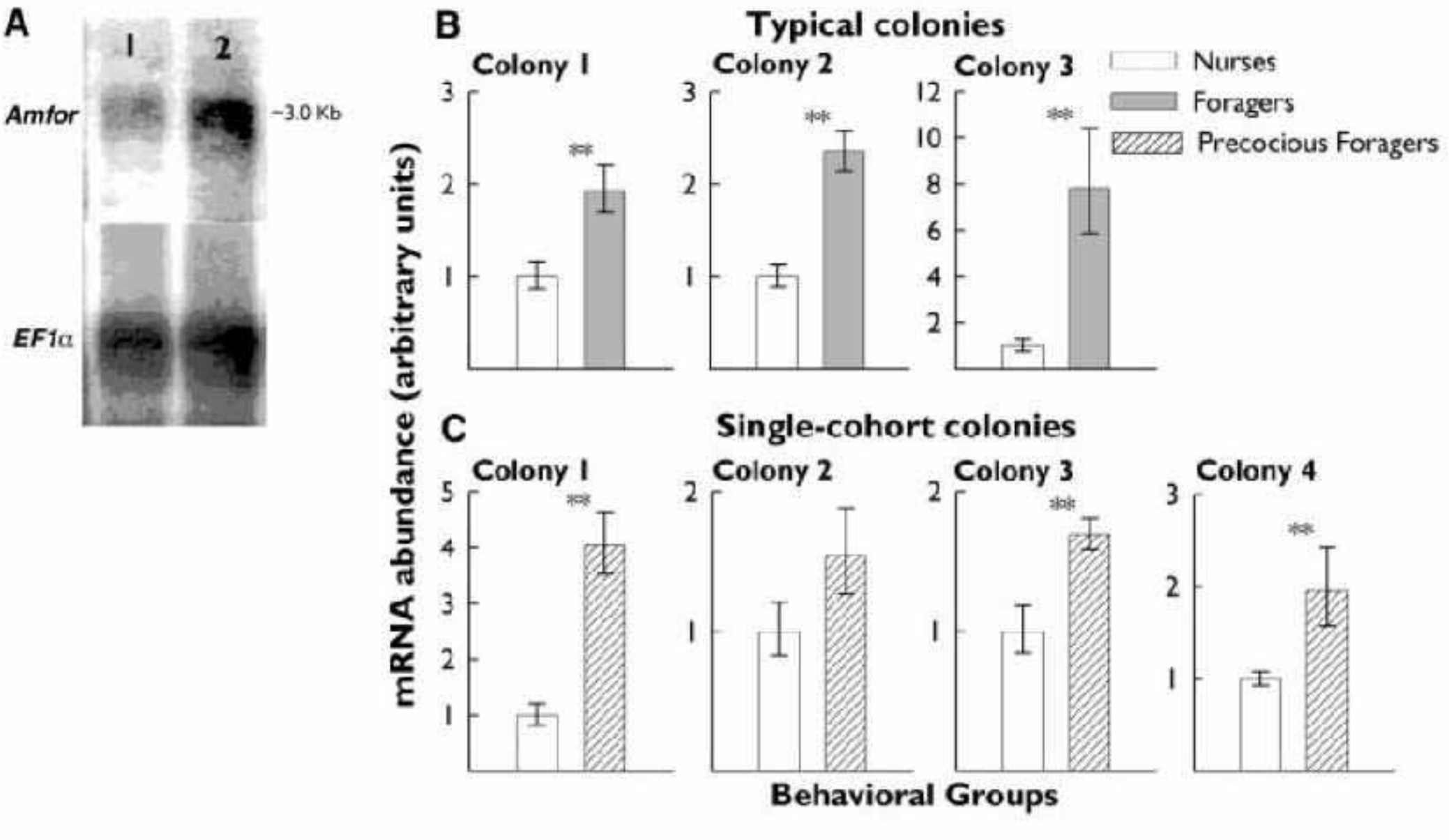




Effects of gene deletions and polymorphisms

In honey bees the ***for*** gene controls when workers change from hive maintenance to foraging

Ben-Shahar *et al* 2002



Social bonding genes

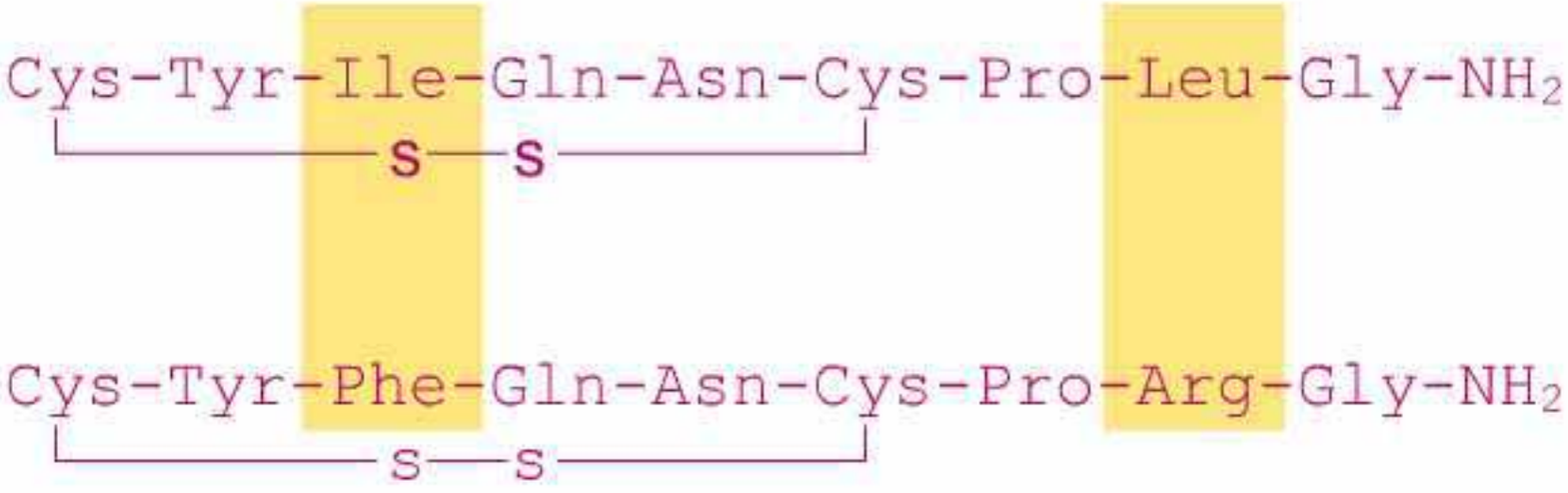
In mammals:
social monogamous vs. asocial promiscuous voles

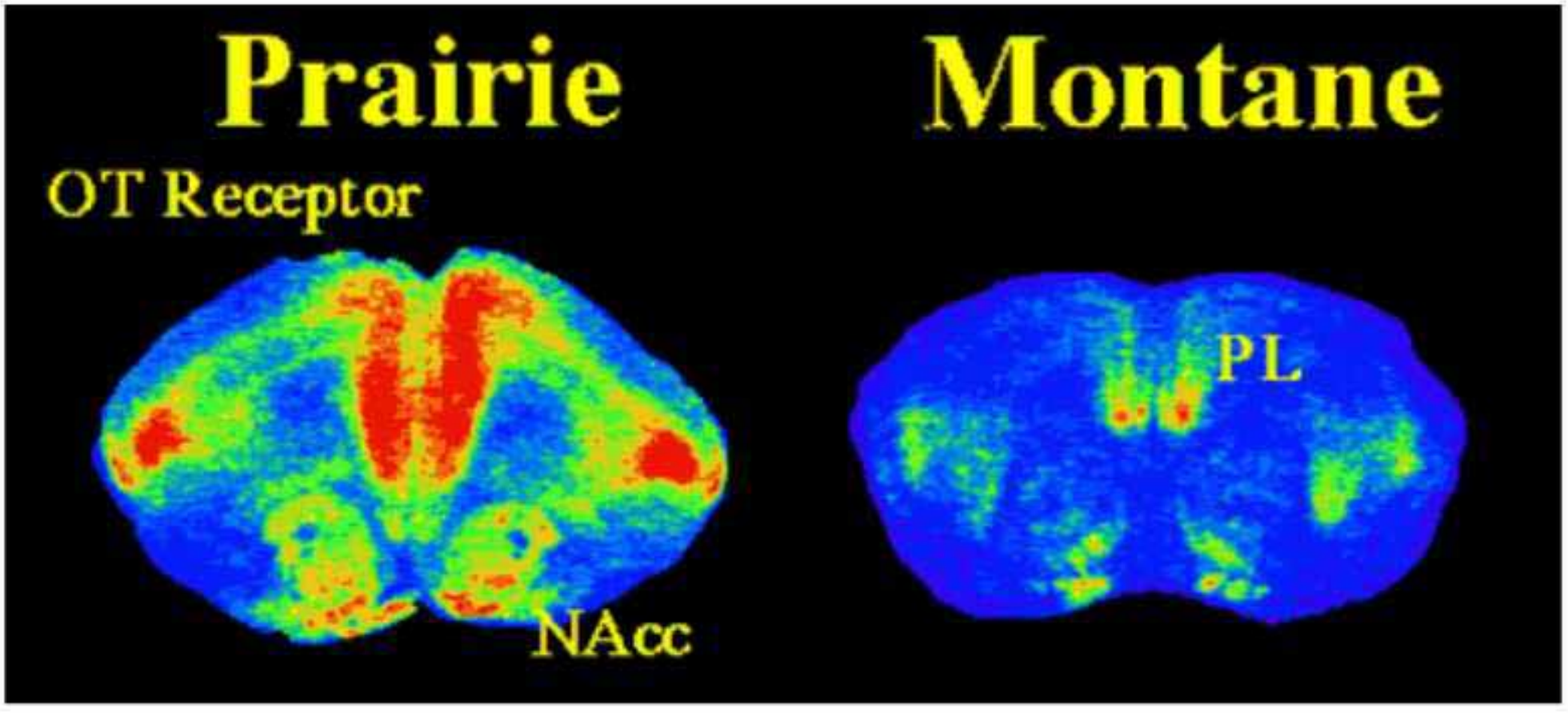
Pine and Prairie voles are highly social, monogamous and show paternal care

Montane and Meadow voles are asocial, promiscuous and show no paternal care

Social bonding genes

Oxytocin and vasopressin and their respective receptors



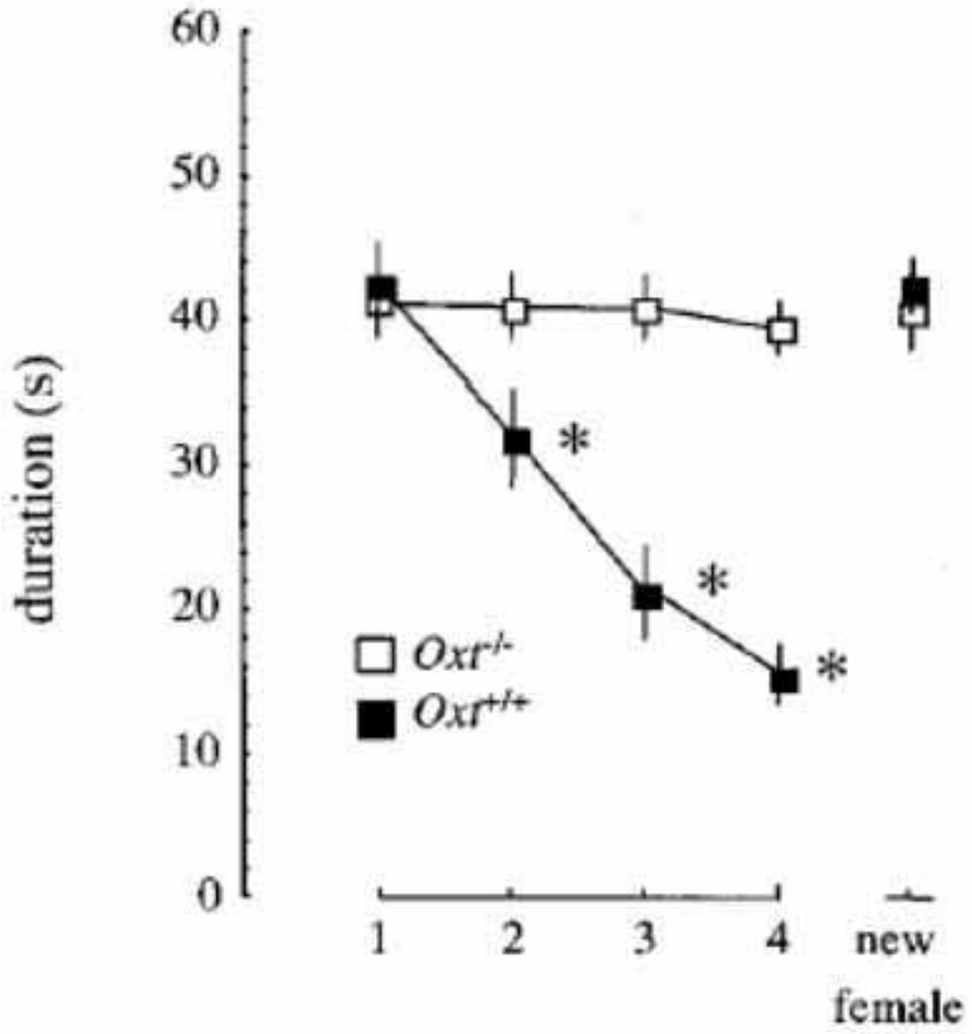


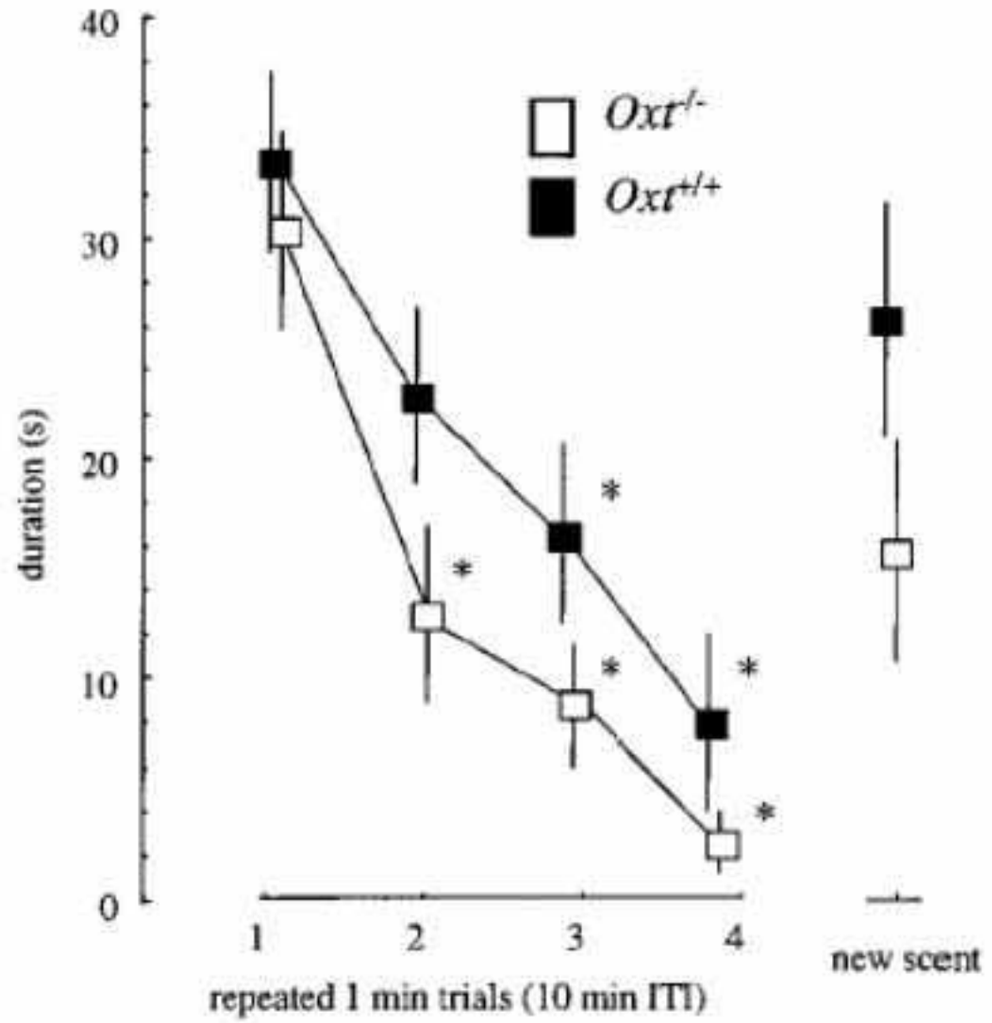
Social bonding genes

Oxytocin and vasopressin and their respective receptors

Social bonding genes

Both peptides promote social recognition memory



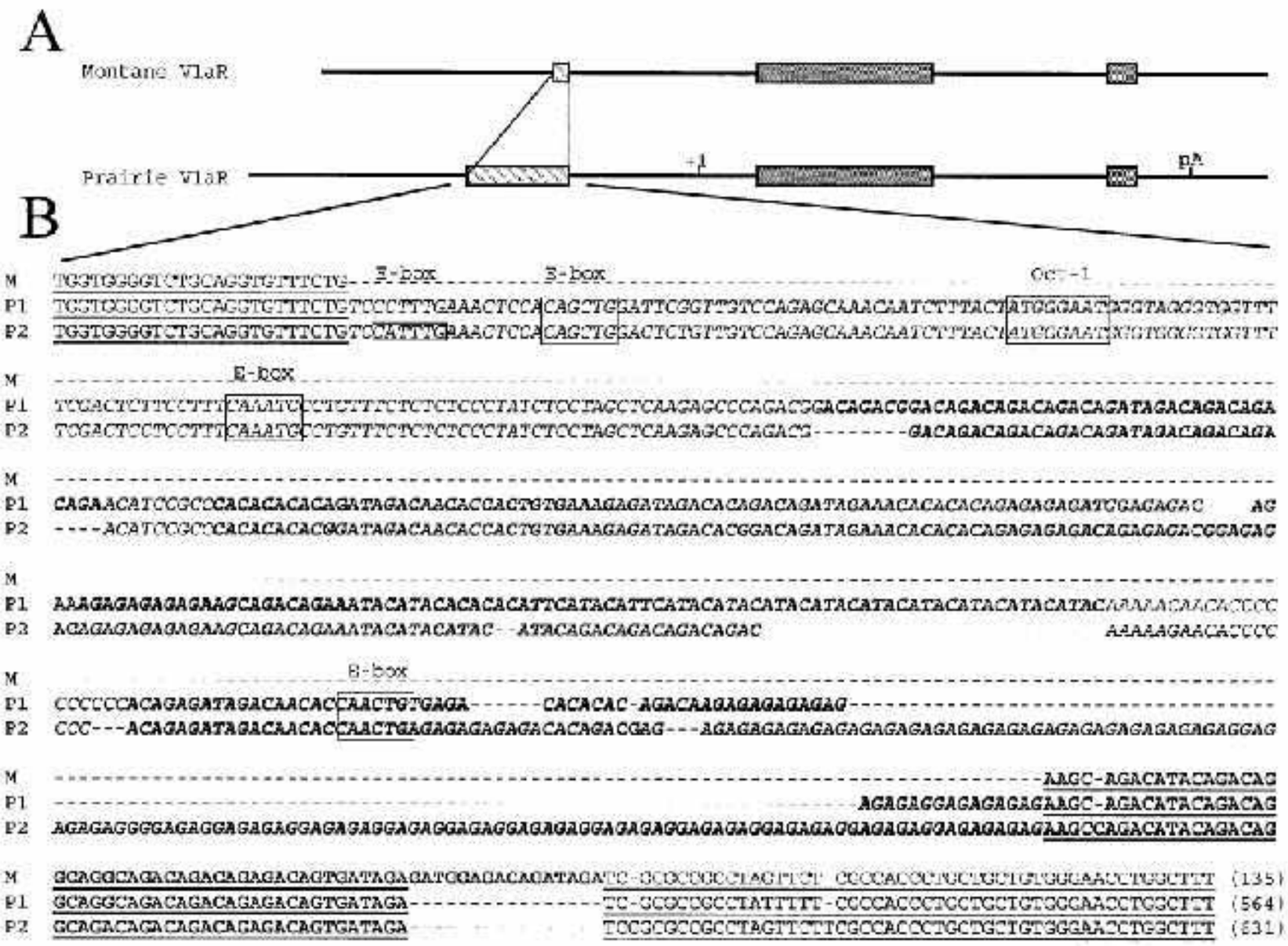


Ferguson *et al* 2000

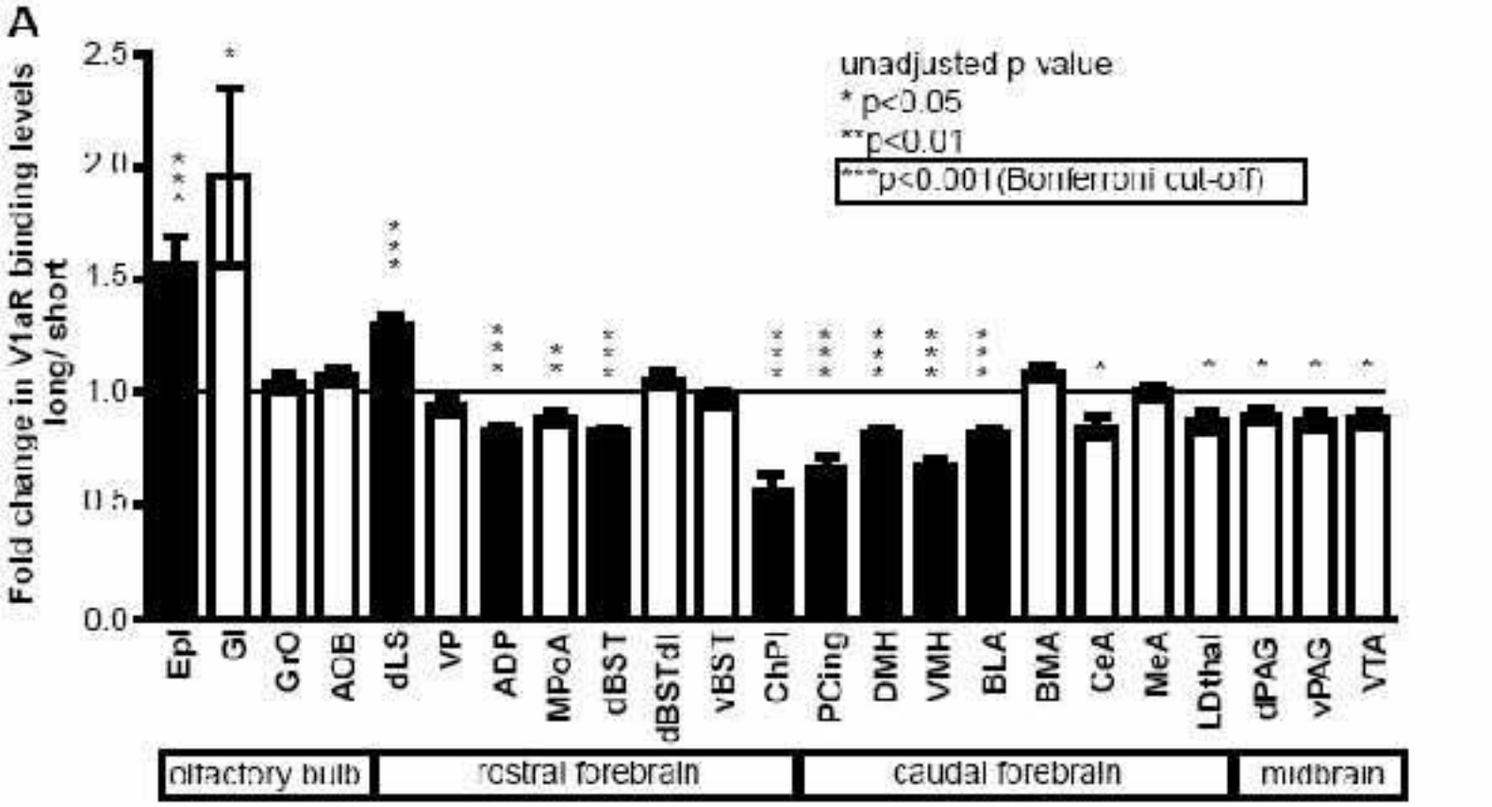
Social bonding genes

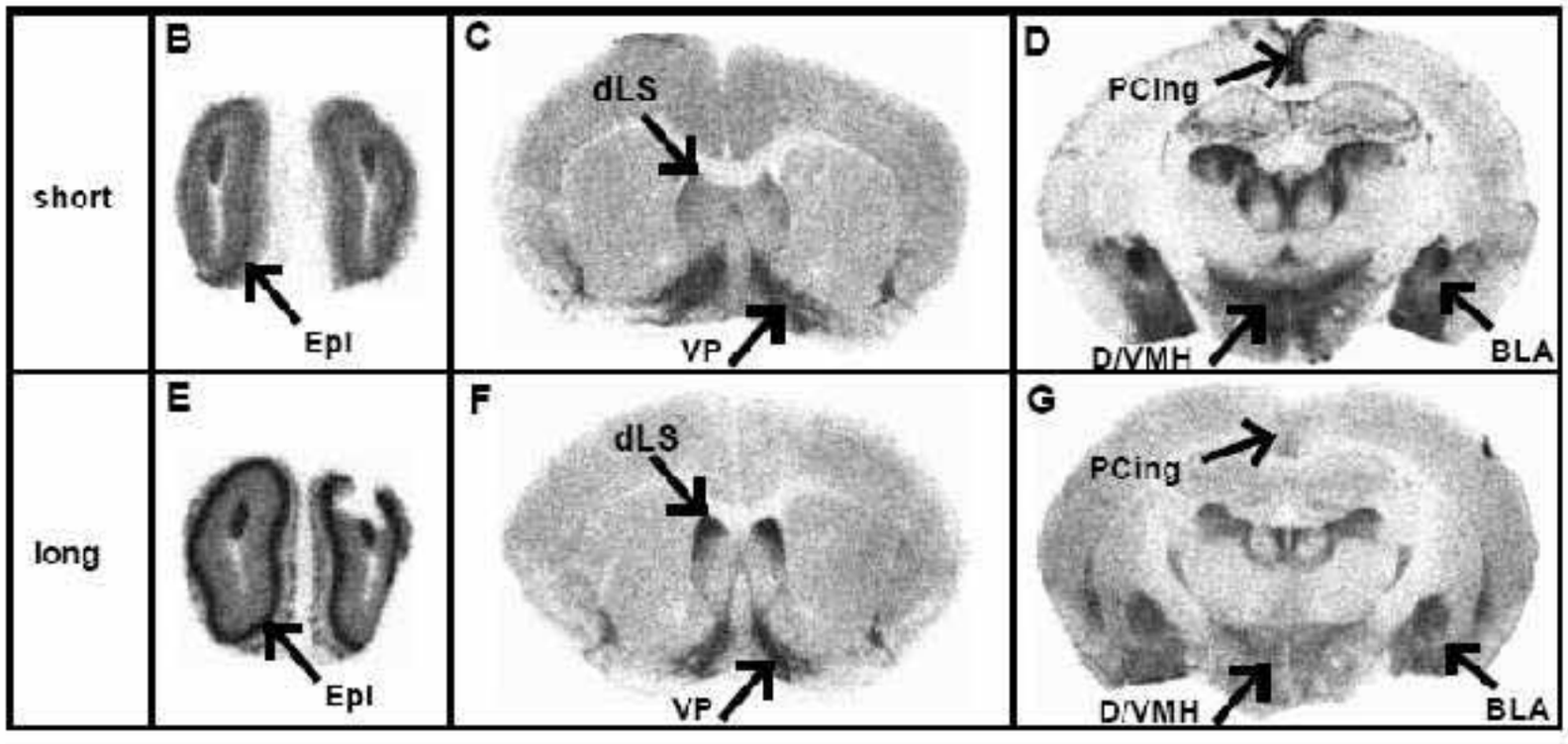
Vasopressin *v1ar* receptor has a polymorphism that promotes its social distribution

Hammock and Young 2002 & 2005

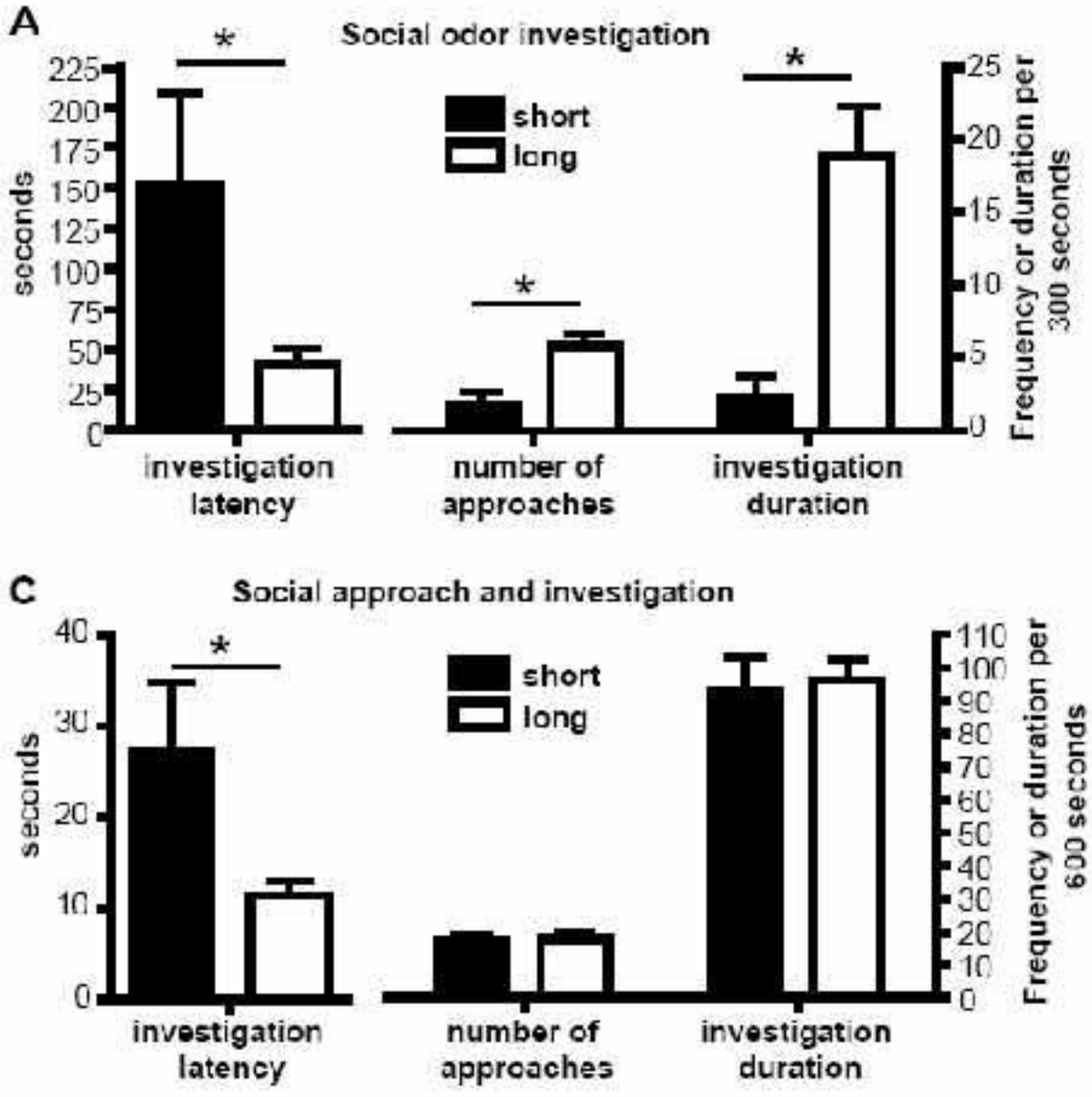


Social bonding genes





Social bonding genes



	PP	EP	SP
long	18	4	10
short	14	5	11

Social bonding genes

Same longer form of the gene is found in Humans and Bonobos but not Chimpanzees

```
                        401                                                                                                  500
      H. sapiens  (394) TGTAAGTGCTGCTCAAAGGCACACTGTTCTCACTTTTAATTTTACCCTATAGAGTAAATAGTATAATGAAGACTTGATGTTTTTTCGTGCTTGACTTGCA
P. troglodytes    (389) TTTAAGTGCTGCTCAAAGGCA-------------------------------------------------------------------------------
     P. paniscus  (387) TGTAAGTGCTGCTCAAAGGCACACTGTTCTTGCTTTTAATTTTACCCTATAGAGTAAATAGTATAATGAAGACTTGATGTTTTTTCATGCTTGACTTGCA

                        501                                                                                                  600
      H. sapiens  (494) GCACTTTTTAGAATCCAGTACACTCTCACTTTCTCTCTCTTTCTCTCTCTCTCTCTCTGTGTGTGTGTGTGTGTGTGTGTGTGTGTGTGTGTGTGTGTGT
P. troglodytes    (410) ----------------------------------------------------------------------------------------------------
     P. paniscus  (487) GCACTTTTTAGAATCCAGCACACTCTCACTTTCTTTCTCTCTCTCTCTCTCTCTGTGTGTGTGTGTGTGTGTGTGTGTGTGT------------------

                        601                                                                                                  700
      H. sapiens  (594) GTGTGTAGTTAAAGAATCTCATACCCTGGATATCTTTTAAAGCCACATATTACACTTACCTGACCAGATTCCCAAGACAGAAGAAAGACTAGAACCATCT
P. troglodytes    (410) ----------------------------------------------------------------------------------------------------
     P. paniscus  (573) GTGTGTAGTTAAAGAATCTCATTCCCTGGATAACTTTTAAAGCCACATATTACACTTACCTGACCAGATTCCCAAGACAGAAGAAAGACTAGAACCATCT
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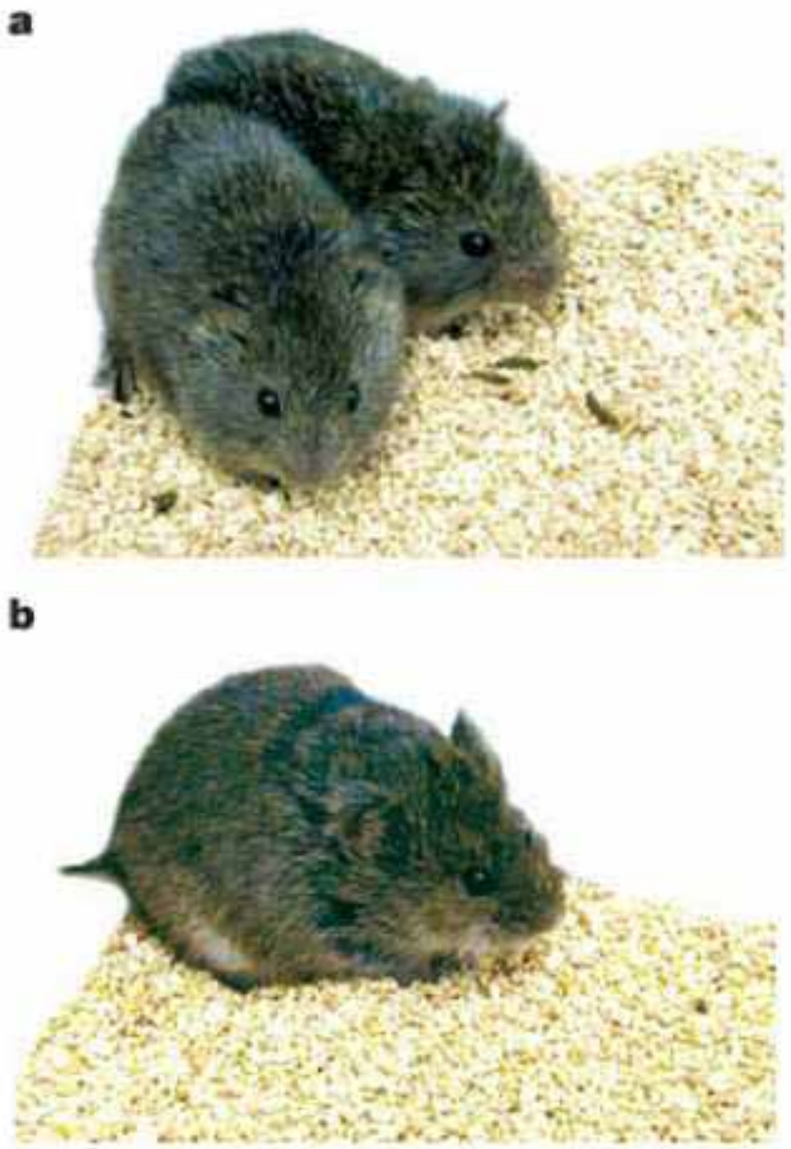
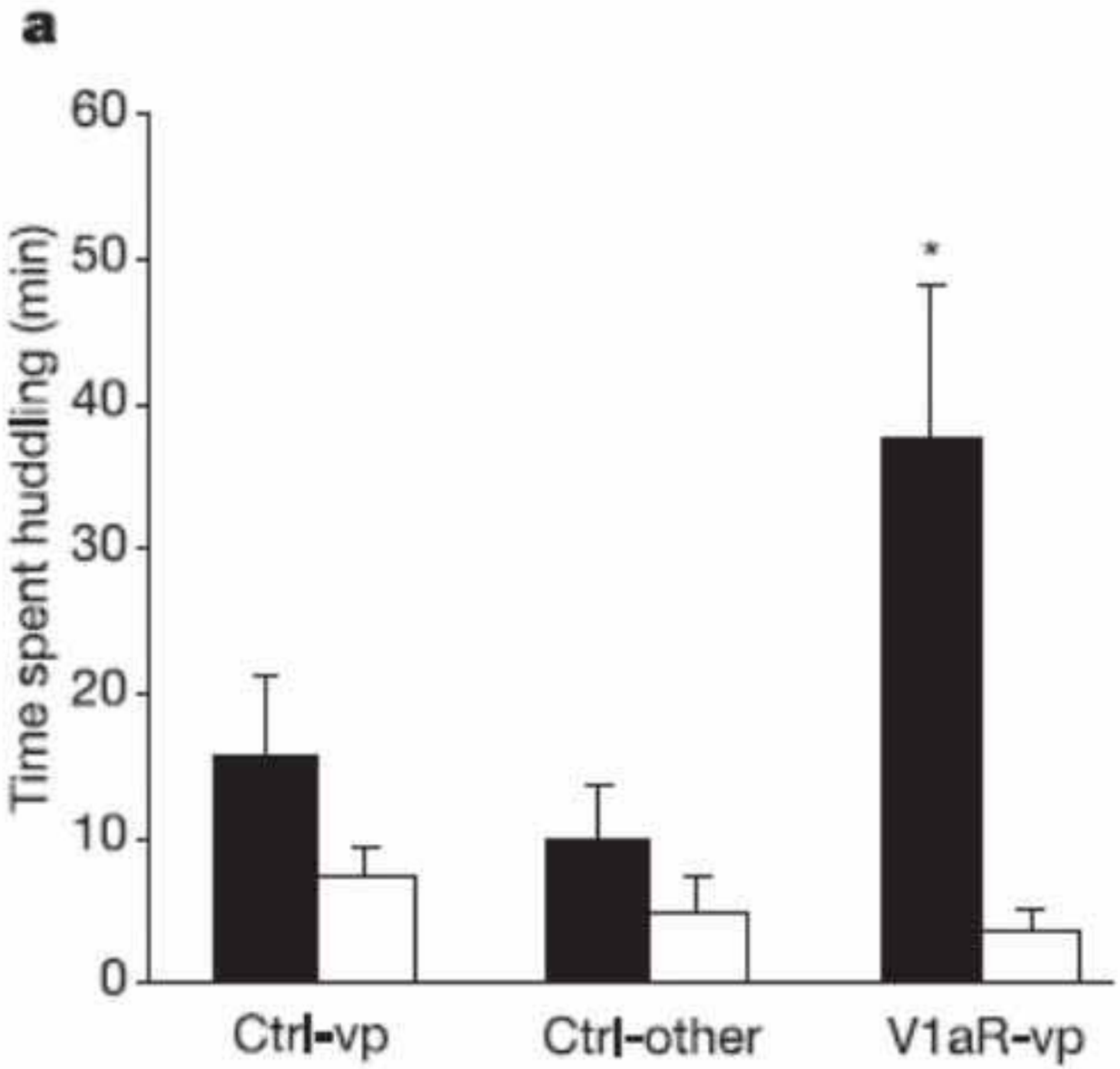
Social bonding genes

Expressing the long form in the brain of an asocial vole makes it become social

Lim *et al* 2004

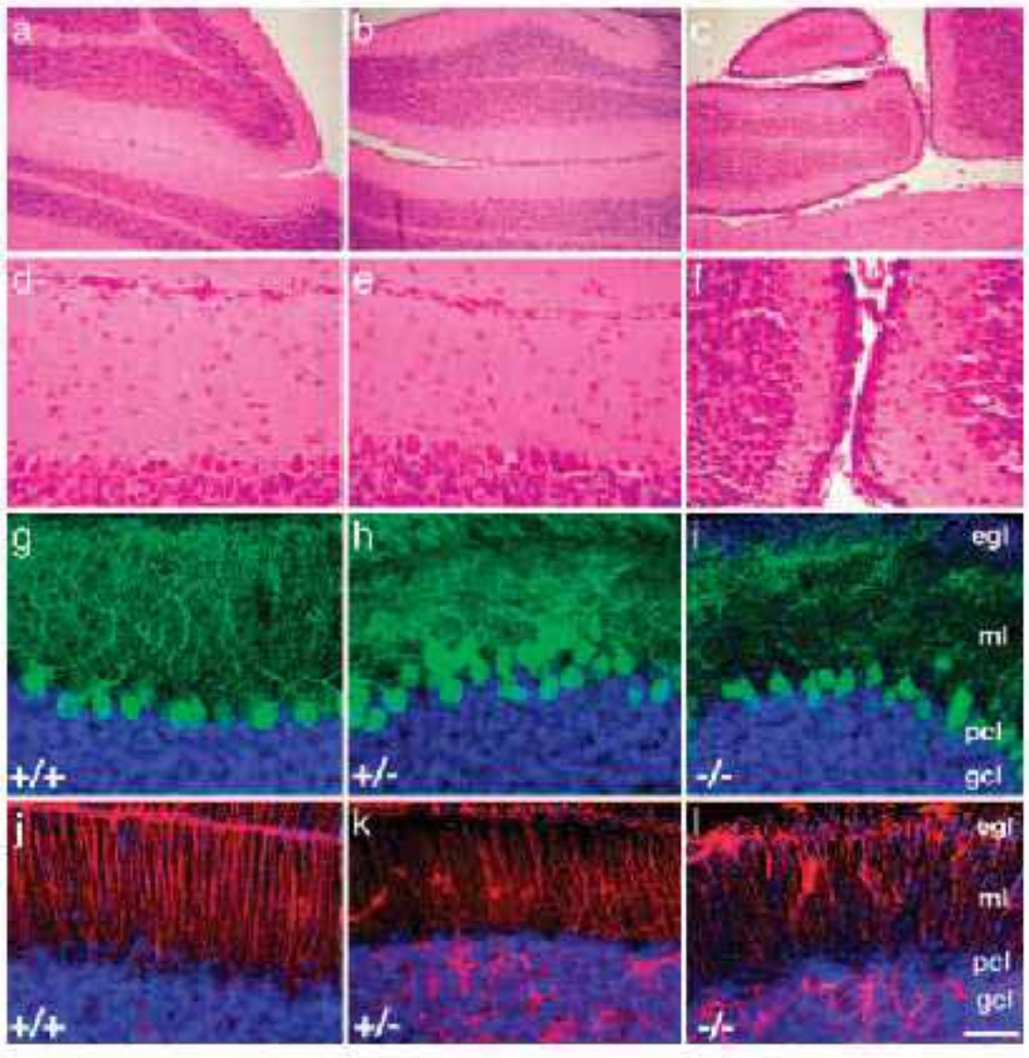


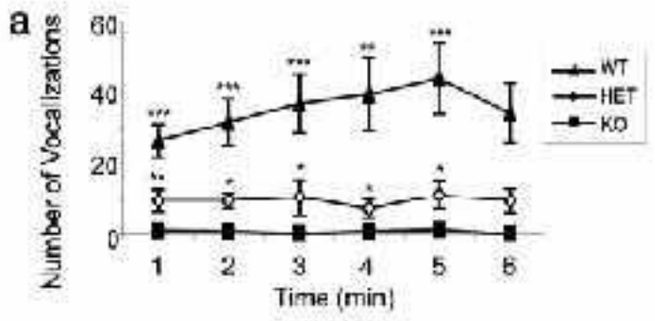


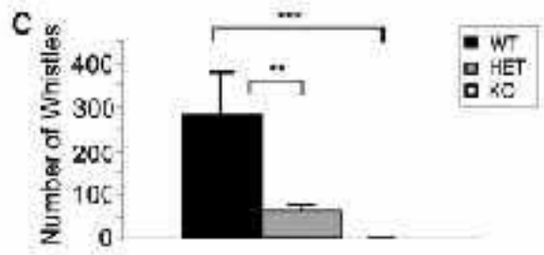
Language genes

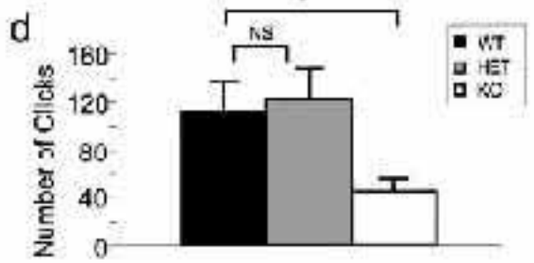
Foxp2 gene language and social communication.

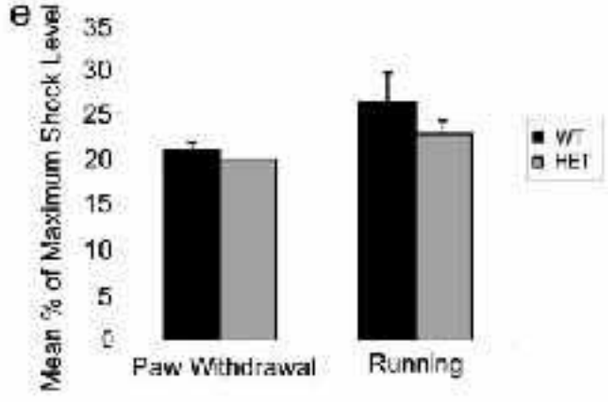
Shu *et al* 2005

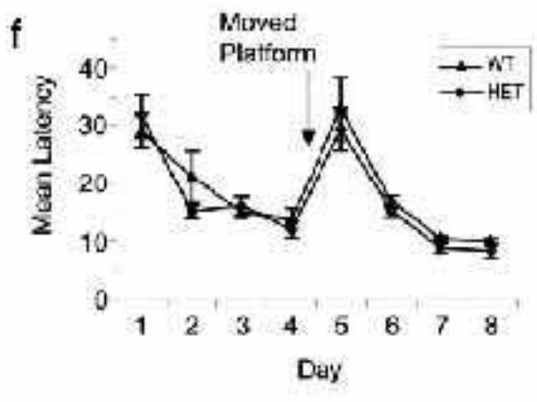












Altruism genes

Gene variant on chromosome 11 linked to altruism

Bachner-Melman *et al* 2005

Scientific Correspondence

Molecular Psychiatry (2005) **10,** 333–335. doi: 10.1038/sj.mp.4001635 Published online 18 January 2005
Published online 18 January 2005

Dopaminergic polymorphisms associated with self-report measures of human altruism: a fresh phenotype for the dopamine D4 receptor

Has the opposite effect on the dopamine D4 receptor as risk-taking

Disorders with social behaviour dysfunction

Many human genetic disorders are associated with social behaviour dysfunction:

Autism and Aspergers

Positive link with the oxytocin receptor gene

Wu *et al* 2005

Table 5. Genetic Association between Haplotype and Autism

Marker	Allele	S	E(S)	Specific Haplotype FBAT		Global Haplotype[a] FBAT	
				Z	p^b	χ^2 (df)	p^b
SNP1-SNP2	A-A	103.680	86.422	2.850	.0044	10.034 (3)	.0183
SNP1-SNP3	A-T	105.761	89.828	2.592	.0095	7.259 (3)	.0641
SNP1-SNP4	A-A	113.797	98.575	2.414	.0158	5.994 (3)	.1119
SNP2-SNP3	A-T	191.407	174.785	2.341	.0192	9.586 (3)	.0224
SNP2-SNP4	A-A	193.692	177.894	2.248	.0246	7.552 (3)	.0562
SNP3-SNP4	T-A	172.965	167.974	0.770	.4412	3.774 (3)	.2869
SNP1-SNP2-SNP3	A-A-T	99.669	81.261	3.102	.0019	17.765 (7)	.0131
SNP1-SNP2-SNP4	A-A-A	101.394	85.142	2.681	.0073	11.079 (7)	.1352
SNP1-SNP3-SNP4	A-T-A	106.423	90.551	2.565	.0103	10.230 (6)	.1153
SNP2-SNP3-SNP4	A-T-A	195.147	177.357	2.496	.0126	15.237 (5)	.0094
SNP1-SNP2-SNP3-SNP4	A-A-T-A	100.199	81.776	3.085	.0020	18.593 (9)	.0289

S, test statistics for the observed number of transmitted alleles; E(S), expected value of *S* under the null hypothesis (i.e., no linkage or association); SNP1, rs2254298; SNP2, rs53576; SNP3, rs2228485; SNP4, rs237911.

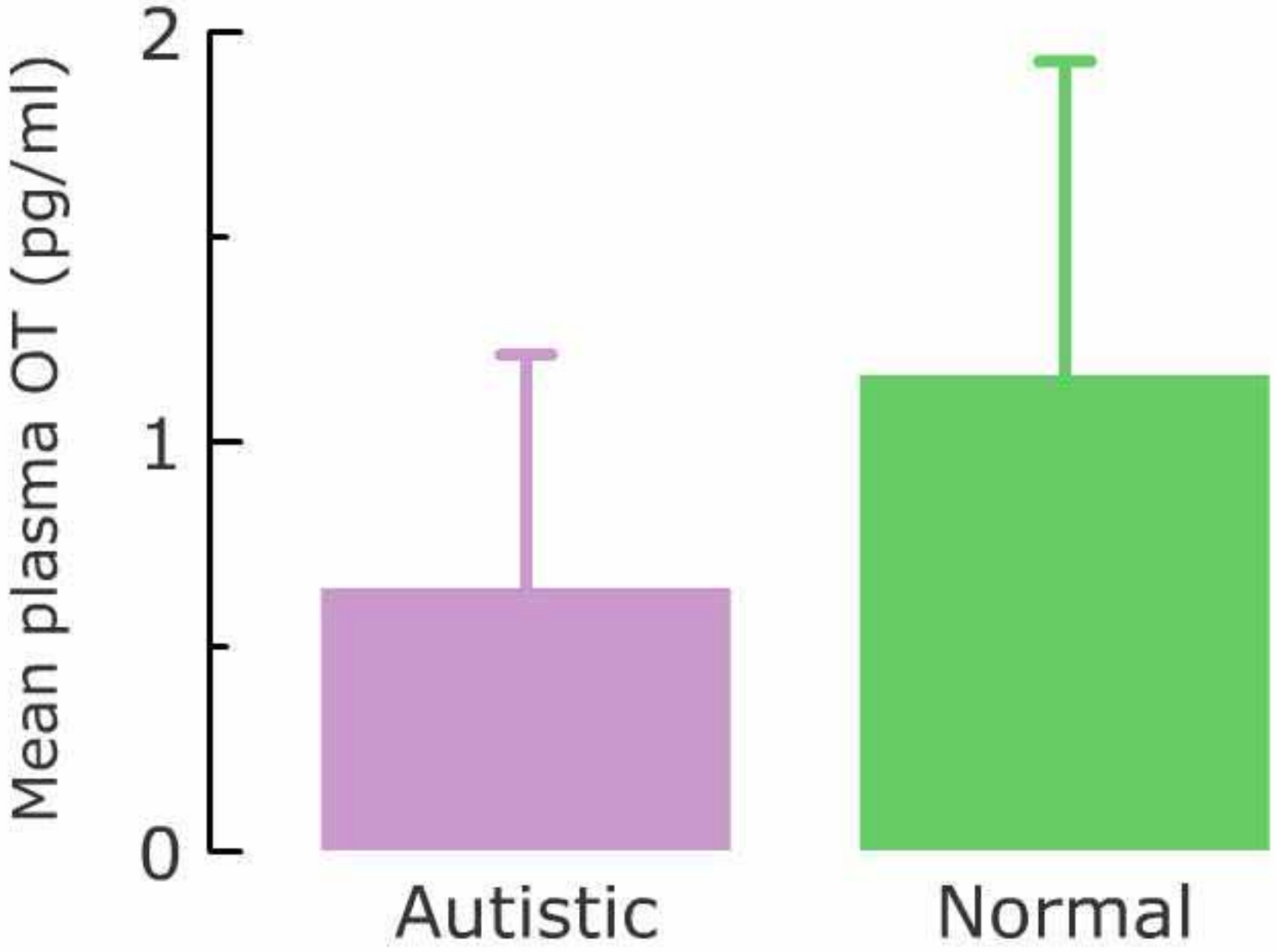
[a]Global haplotype represents the haplotype using all possible variants.

[b]*p*, one-tailed.

Disorders with social behaviour dysfunction

Blood oxytocin levels are lower in autistic than control children

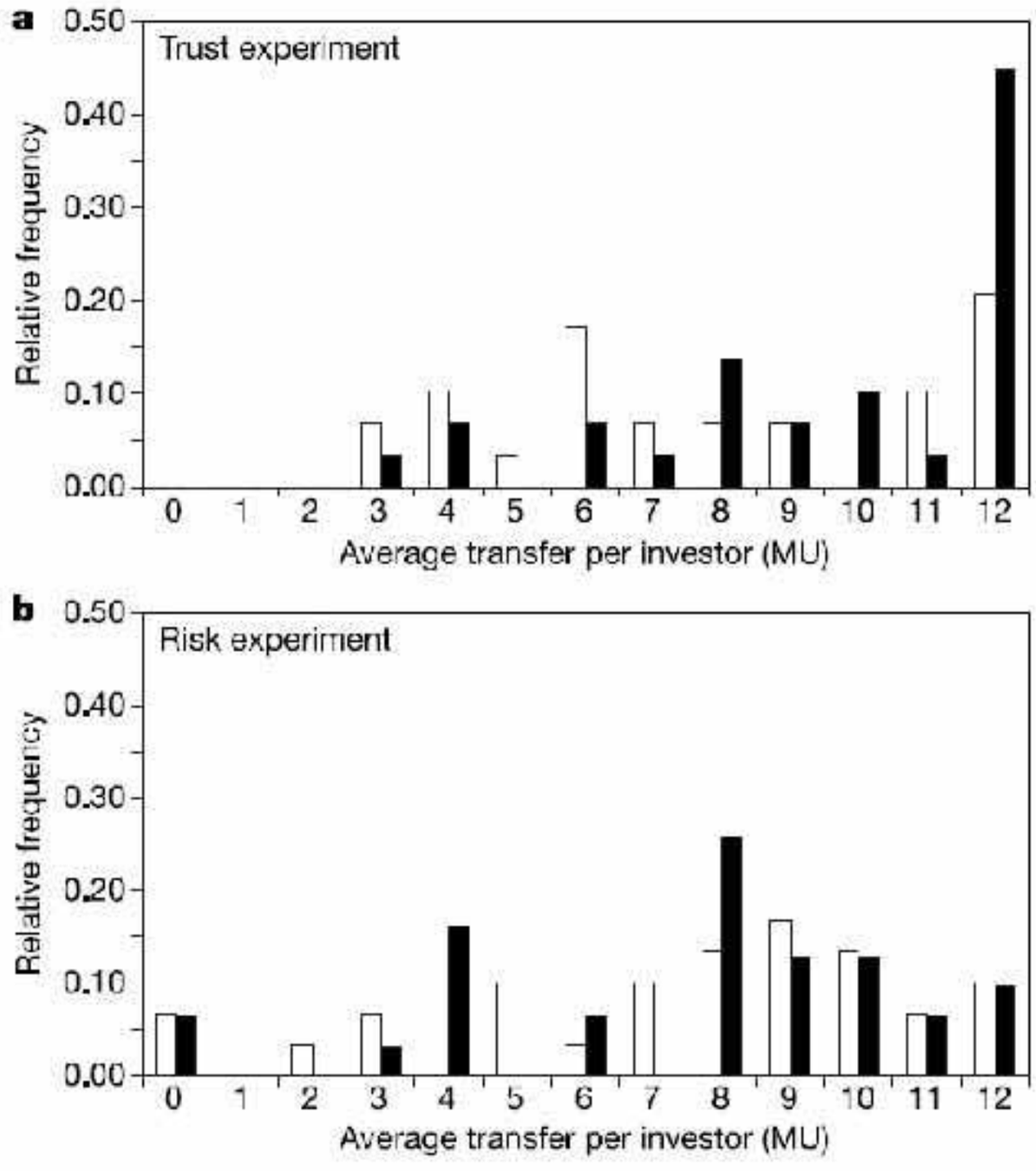
Modahl *et al* 1998



Disorders with social behaviour dysfunction

Intranasal infusions of oxytocin promote social trust

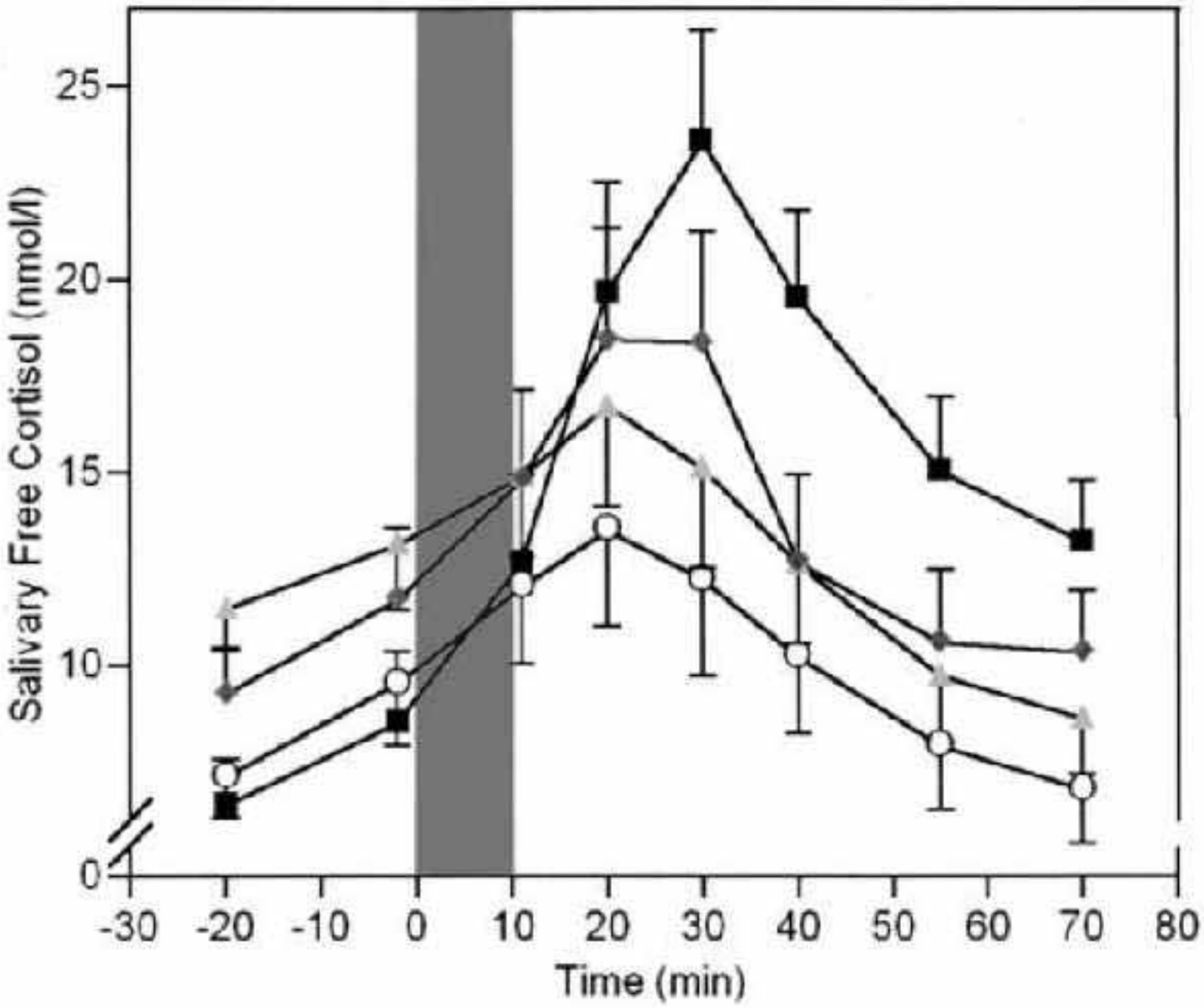
Kosfeld et al 2005

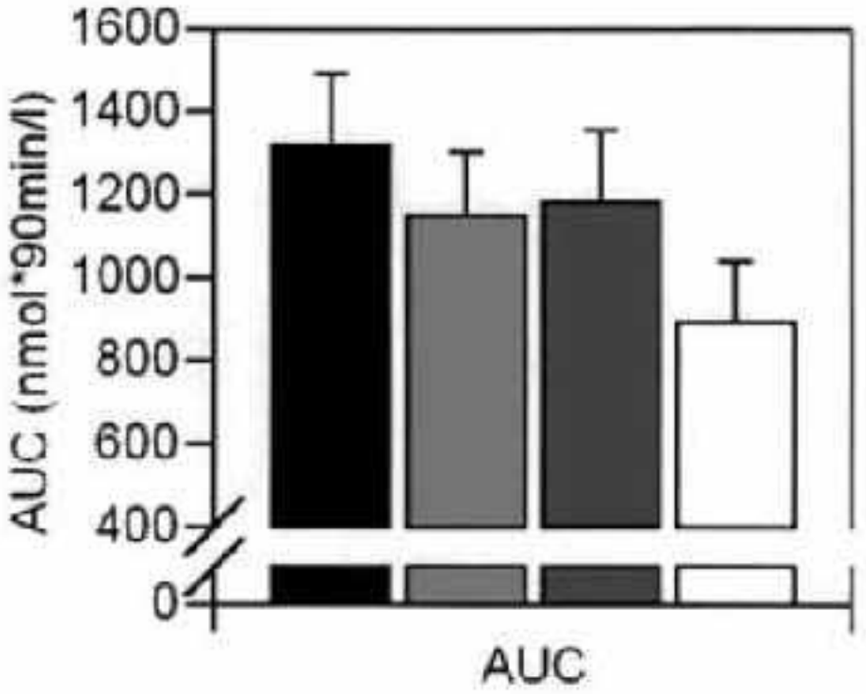


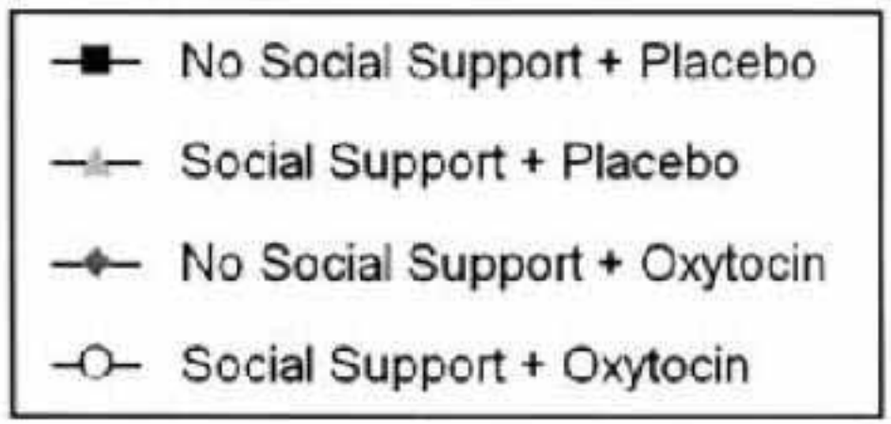
Disorders with social behaviour dysfunction

Increase resistance to psychosocial stress

Heinrichs *et al* 2003



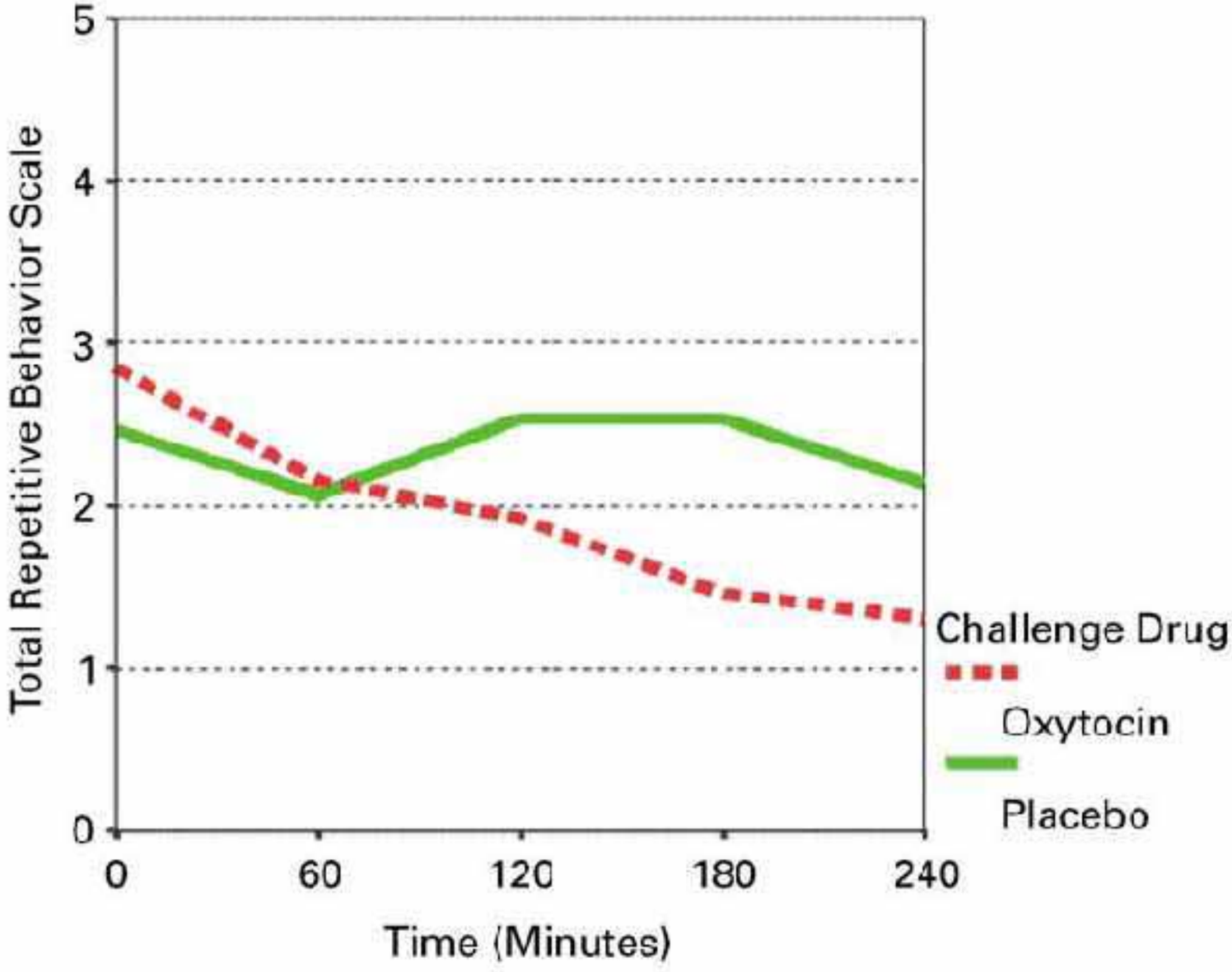




Disorders with social behaviour dysfunction

Reduce repetitive antisocial behaviours in autistic individuals

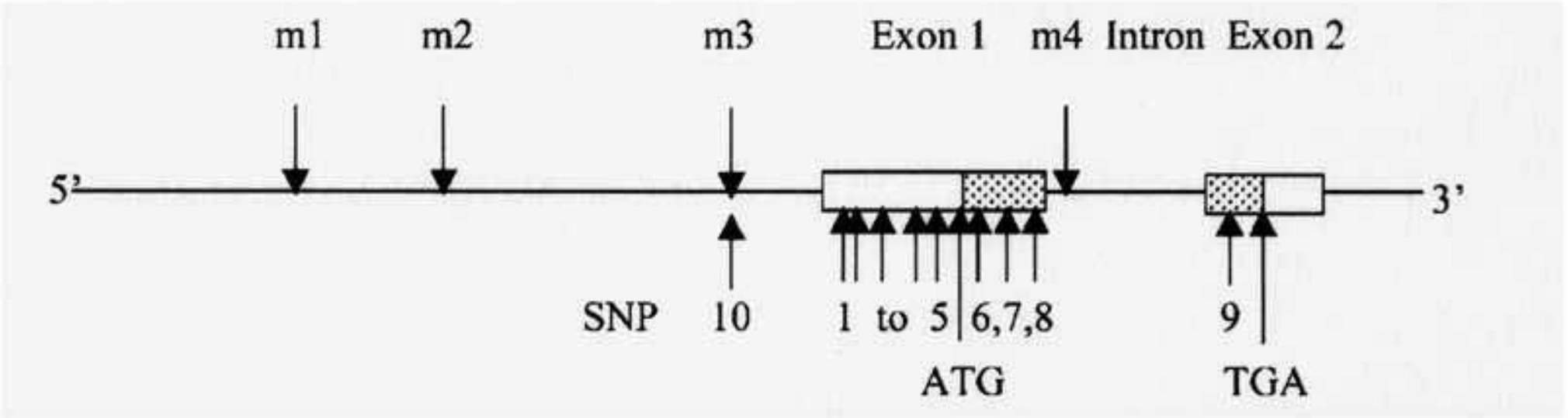
Hollander *et al* 2003



Disorders with social behaviour dysfunction

The human vasopressin receptor gene (***avpr1a***) is also linked to autism

Kim *et al* 2001



The link was strongest in autistic individuals without language impairment

Disorders with social behaviour dysfunction

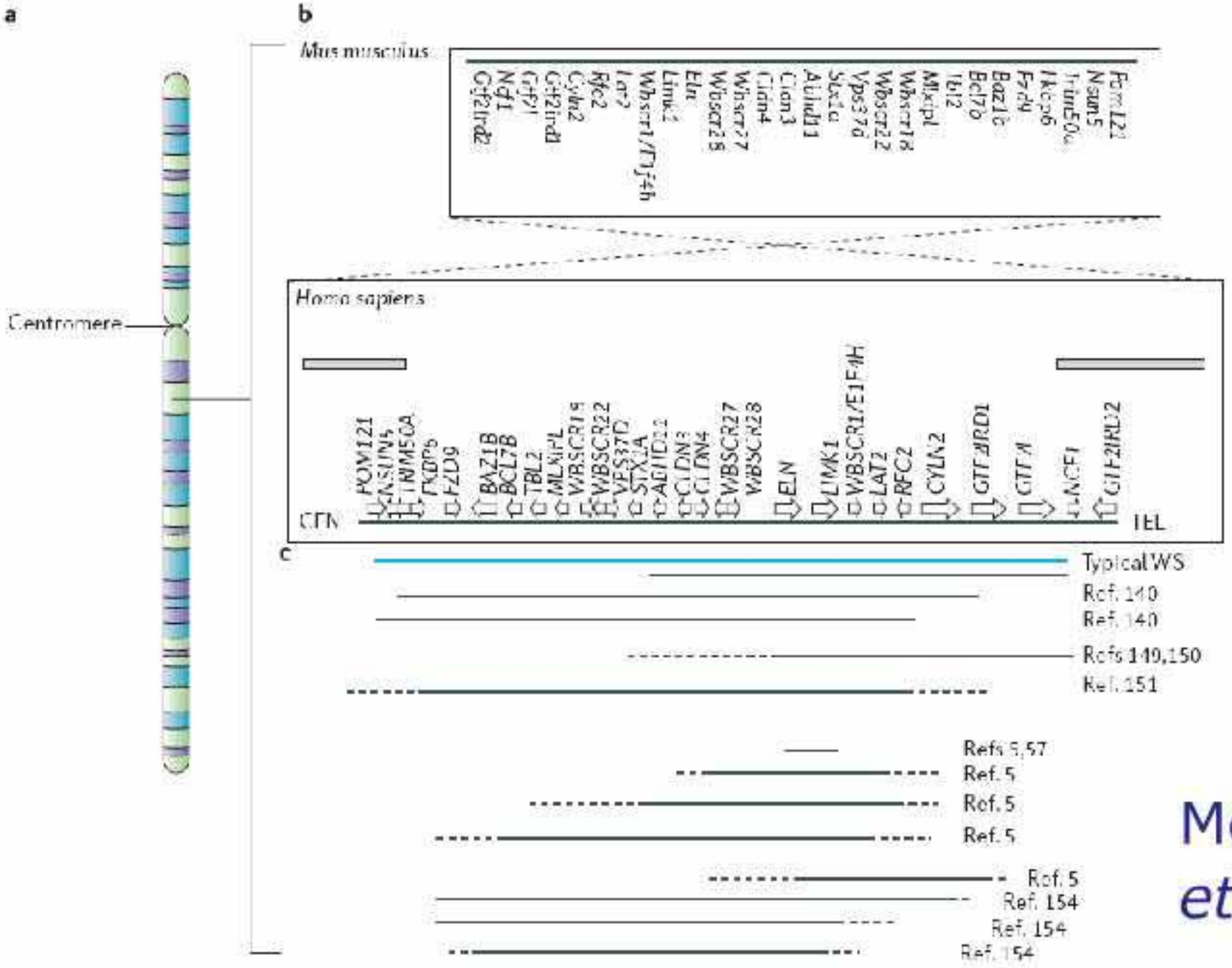
William's syndrome

Mild to moderate mental retardation, cardiovascular abnormalities, growth retardation and a distinct facial appearance

Affects 1 in 7,500 individuals

Disorders with social behaviour dysfunction

Neurodevelopmental disorder with deletion of 28 genes on chromosome 7



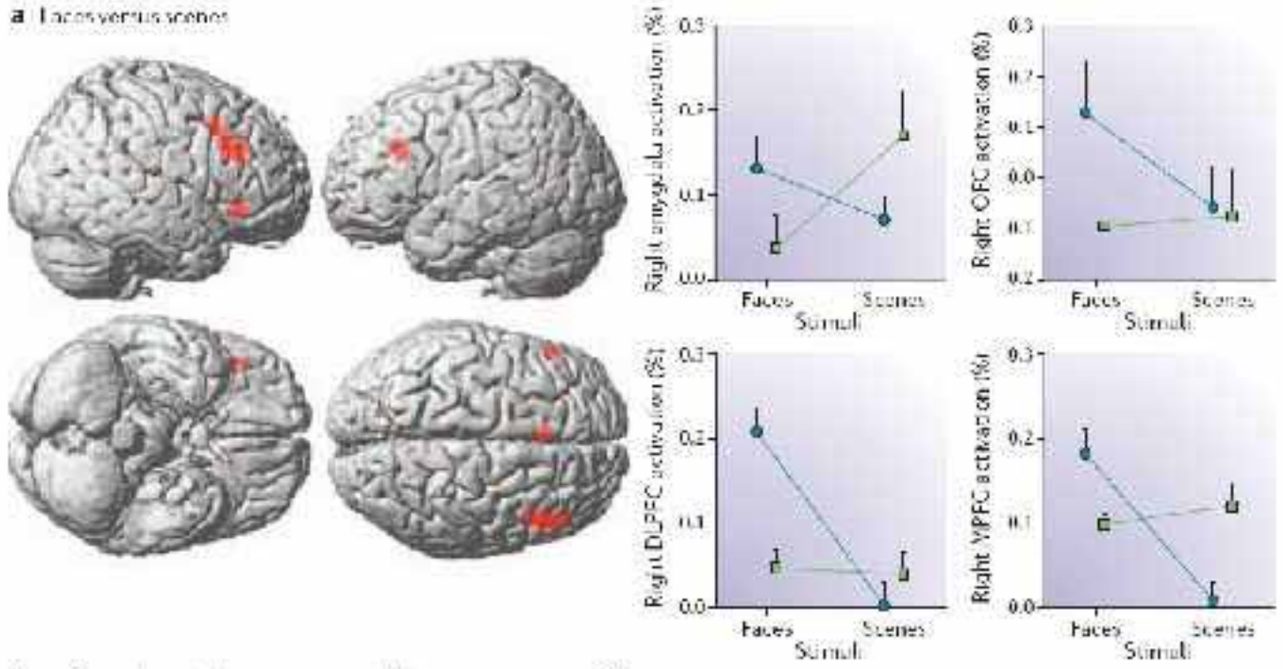
Meyer-Lindenberg *et al* 2006

Disorders with social behaviour dysfunction

Neurodevelopmental disorder with deletion of 28 genes on chromosome 7

Reduced responsivity of the amygdala to threatening faces but not scenes

Meyer-Lindenberg *et al* 2006



Disorders with social behaviour dysfunction

Sufferers are distinctive - highly gregarious and social, with increased empathy and overfriendliness

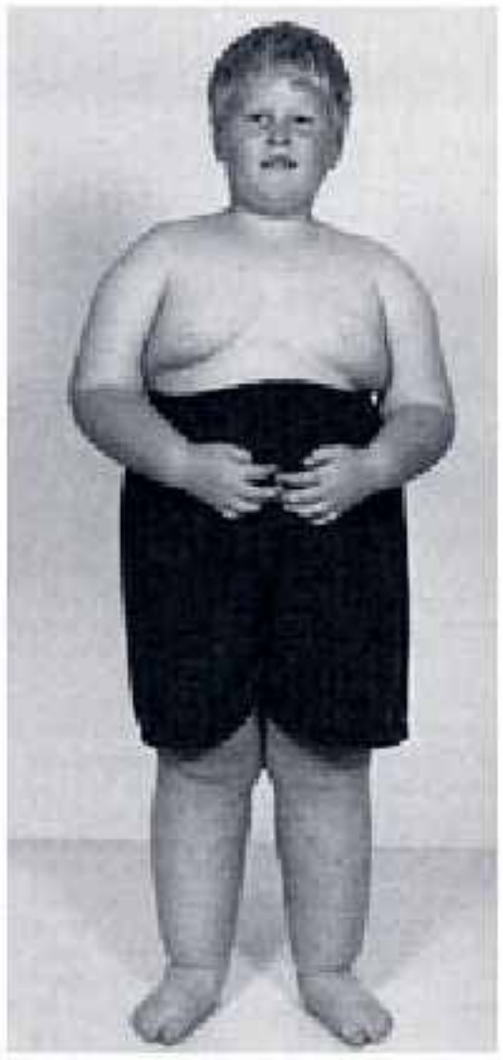
Although they always happy they are actually anxiety-prone in non-social contexts





Disorders with social behaviour dysfunction

Angelman and Prader-Willi syndromes:



Complex genetic disorders causing mental retardation, growth and motor problems

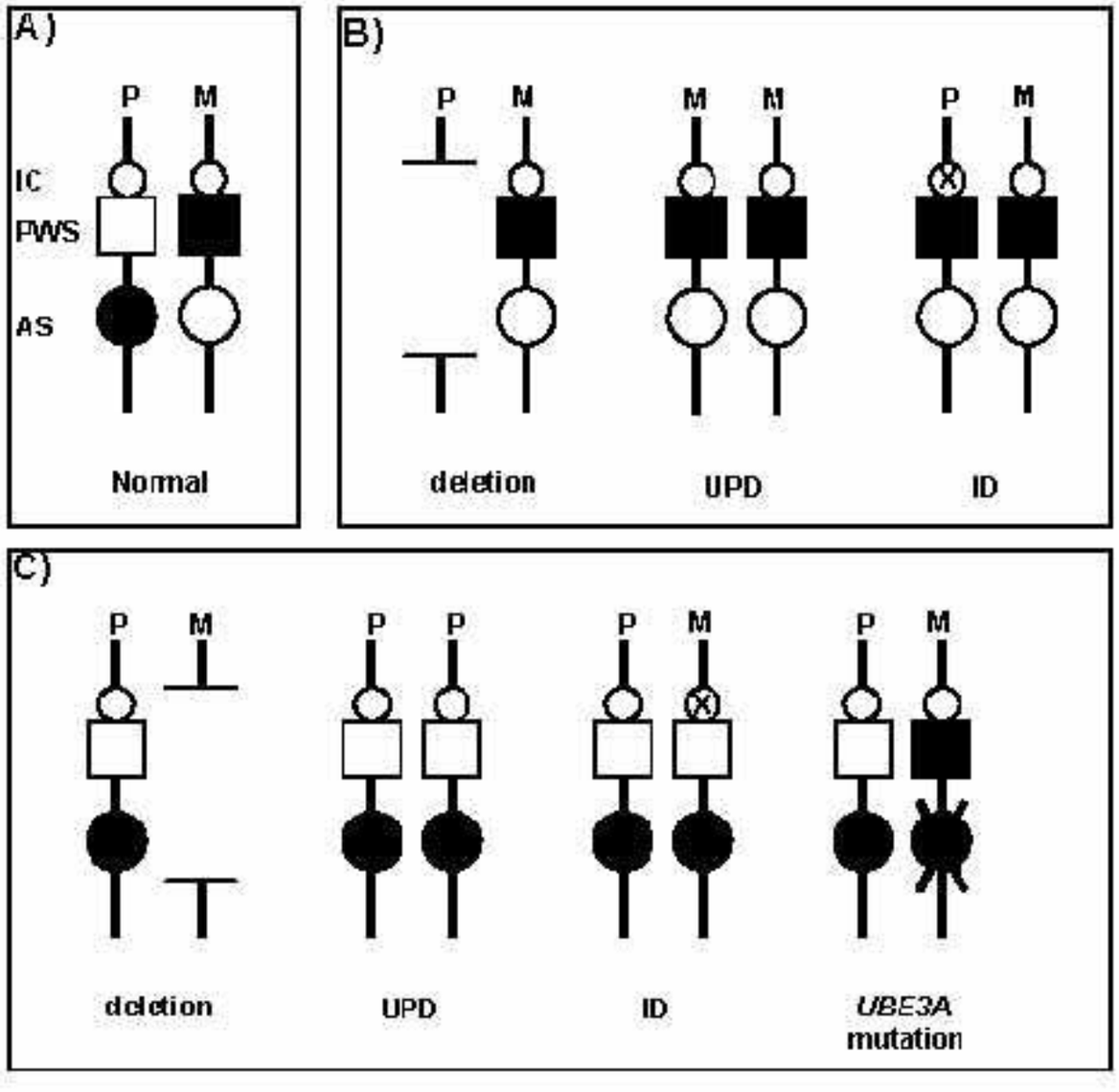
Both result from abnormalities in a region of chromosome 15

Disorders with social behaviour dysfunction

They are associated with imprinted genes:

Prader-Willi involves loss of paternally expressed genes

Angelman involves loss of maternally expressed genes - notably *UBE3A*



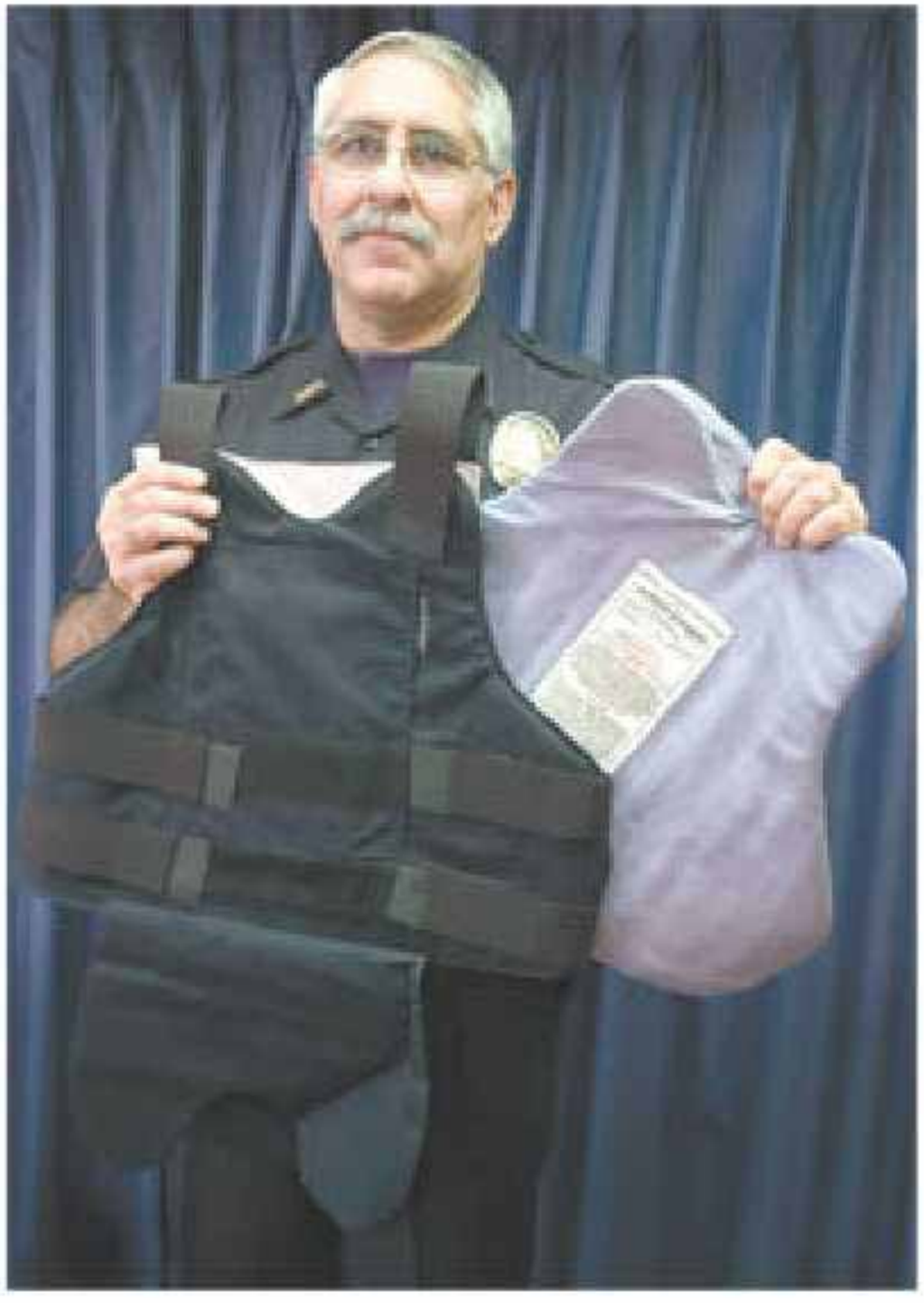
Disorders with social behaviour dysfunction

Angelman syndrome is associated with excessively happy, smiling demeanour and inappropriate laughter

Prader-Willi syndrome is associated with temper tantrums and obsessive compulsive mannerisms

Disorders with social behaviour dysfunction

Sexual conflict theory?

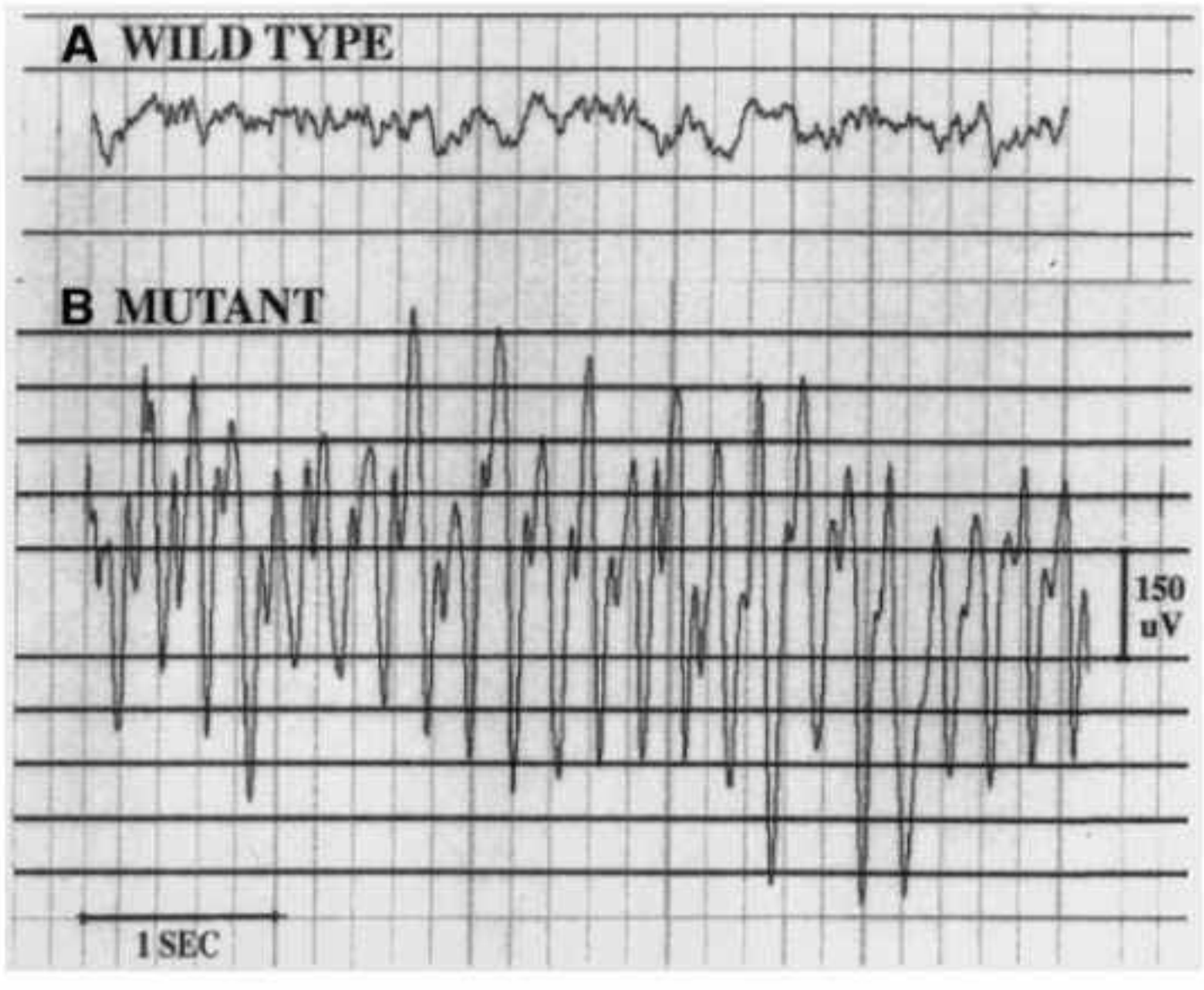


Disorders with social behaviour dysfunction

Sexual conflict theory?

Mice lacking UBE3A gene have cognitive problems and abnormal brain EEG

Miura *et al* 2002



Epigenetic contributions to social behaviour

Effects of maternal nurturing behaviour

Meaney *et al*

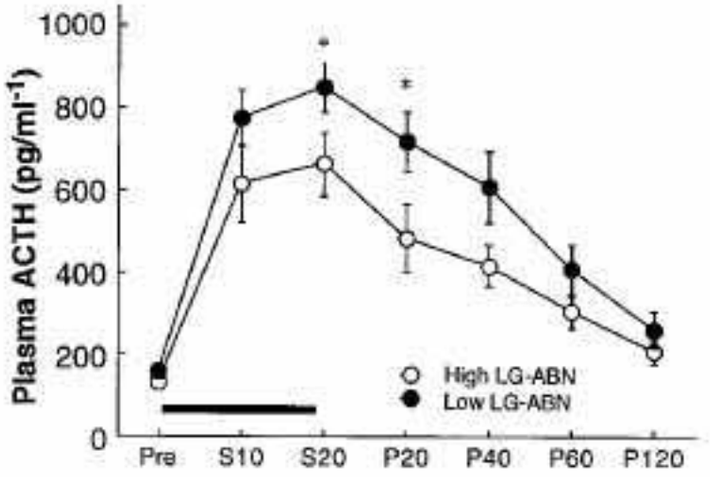
Epigenetic contributions to social behaviour

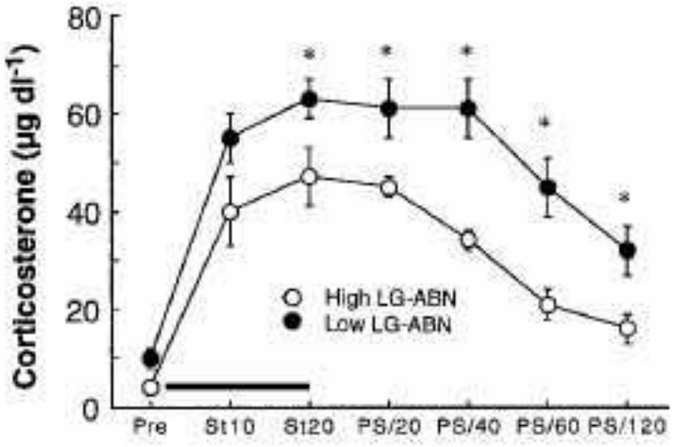
Effects of maternal nurturing behaviour

Low nurturing experience causes higher stress response

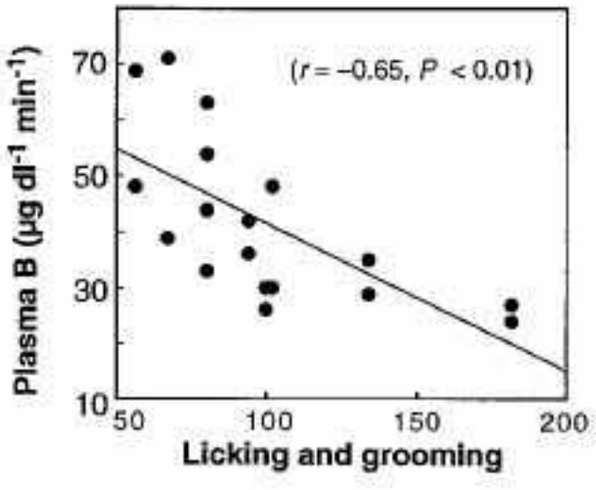
Prevented by cross-fostering

Only affected during first week after birth





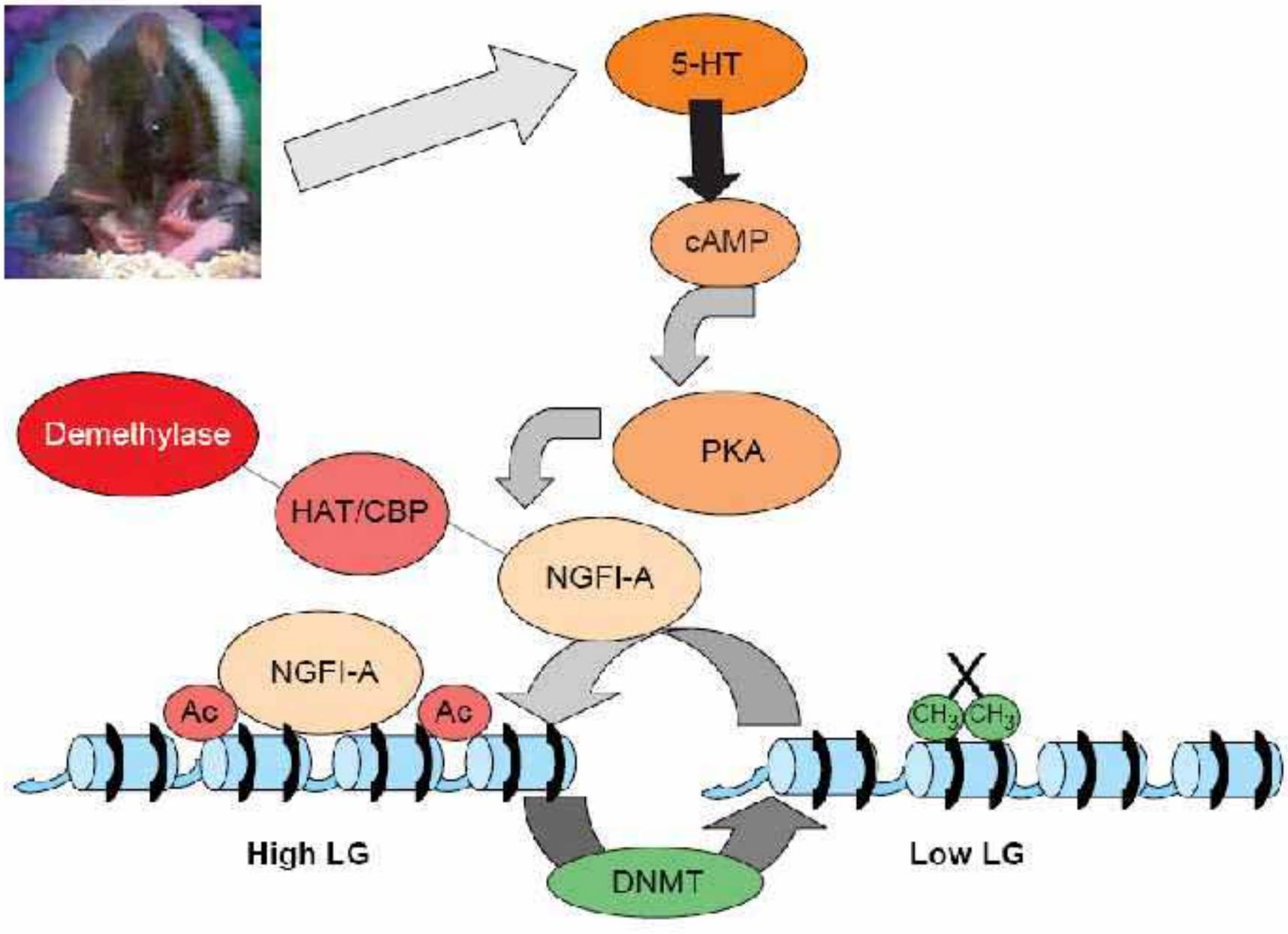
Dong Liu *et al* 1997



Epigenetic contributions to social behaviour

Mediated by altered epigenetic marks on the glucocorticoid receptor (GR) gene

Meaney and Szyf 2005



Epigenetic contributions to social behaviour

Mediated by altered epigenetic marks on the glucocorticoid receptor (GR) gene

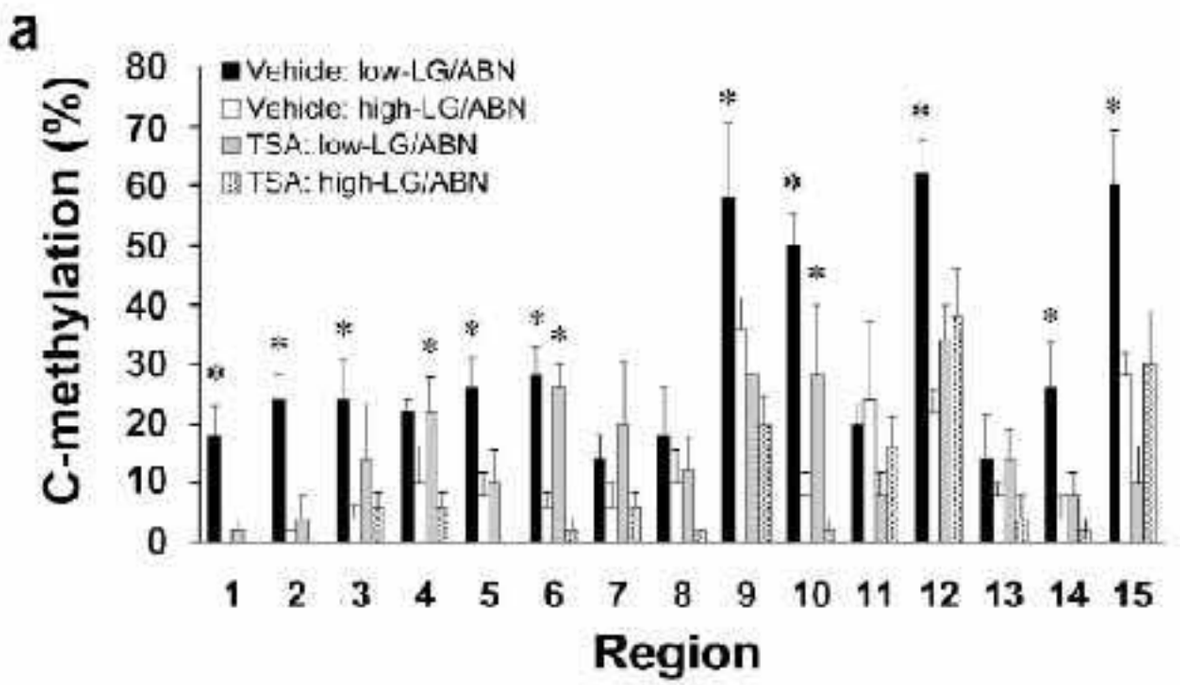
Meaney and Szyf 2005

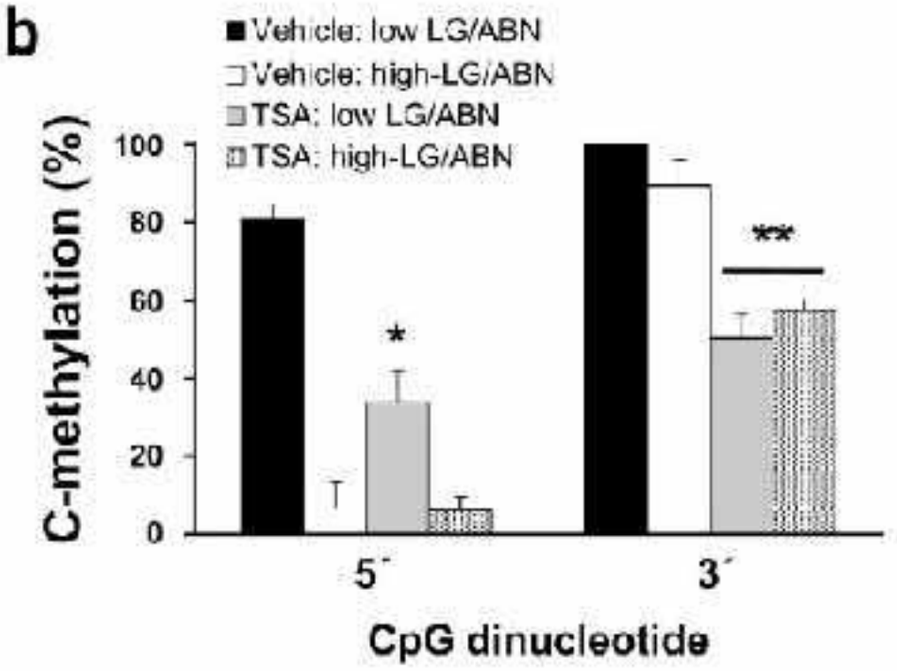
Methylation across the GR promoter region increased in low nurtured animals

Epigenetic contributions to social behaviour

Removing epigenetic marks with a histone deacetylase inhibitor, trichostatin A, reverses behavioural effects

Weaver *et al*
2004 and 2006





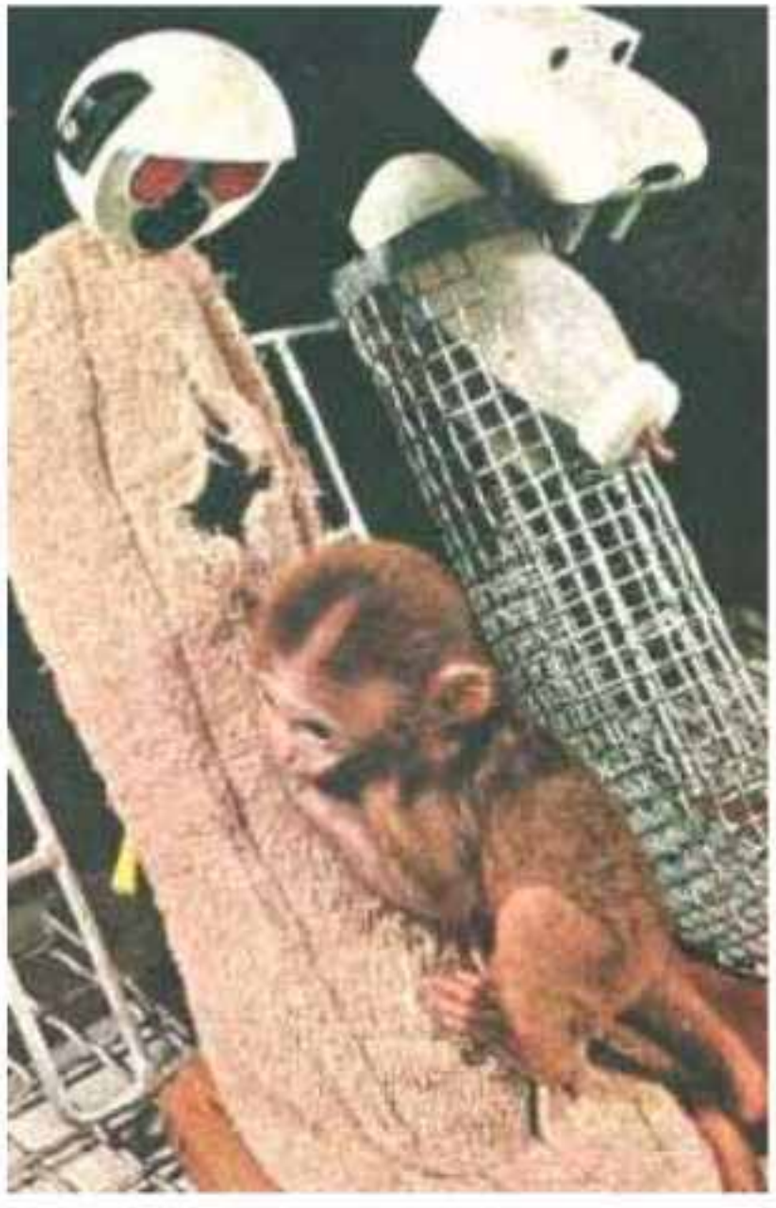
Epigenetic contributions to social behaviour

The critical component of maternal nurturing is simple tactile stimulation

Epigenetic contributions to social behaviour

The critical component of maternal nurturing is simple tactile stimulation

This is at the heart of all social interactions and stimulated by pro-bonding peptides

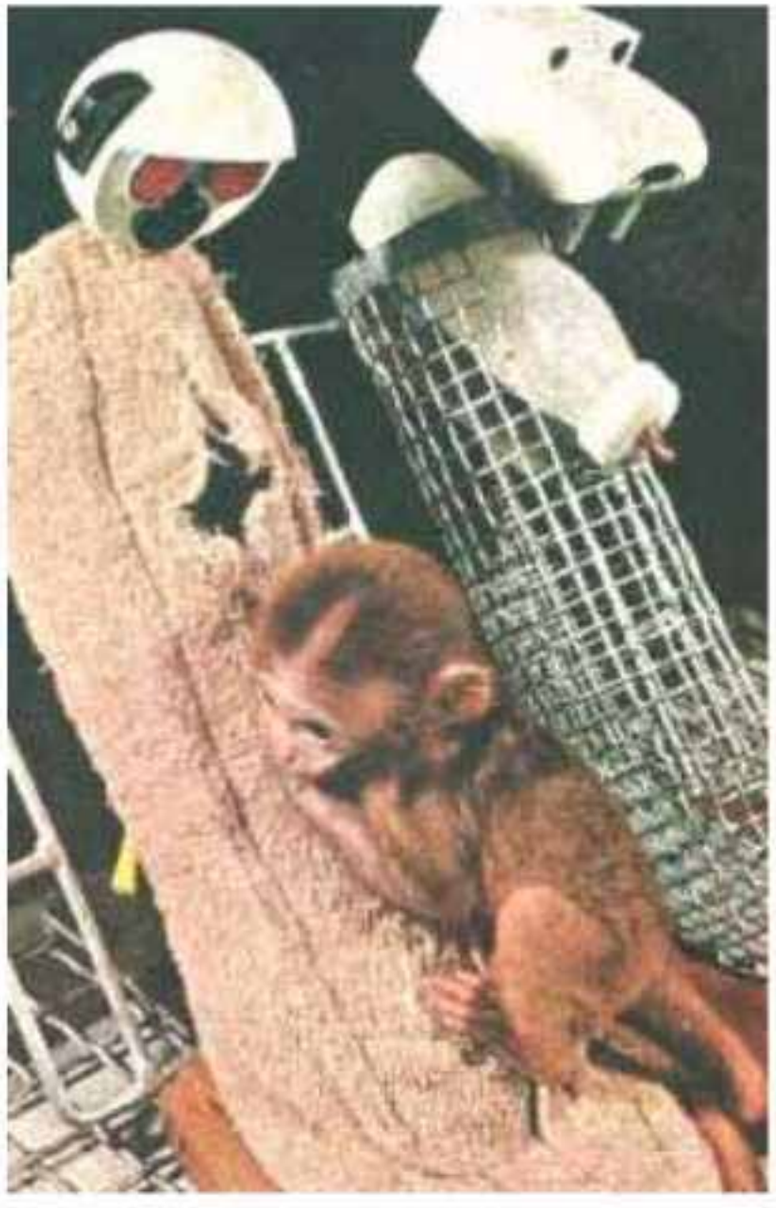


Epigenetic contributions to social behaviour

The critical component of maternal nurturing is simple tactile stimulation

This is at the heart of all social interactions and stimulated by pro-bonding peptides

In many modern cultures mutual tactile stimulation has decreased



Other epigenetic effects?

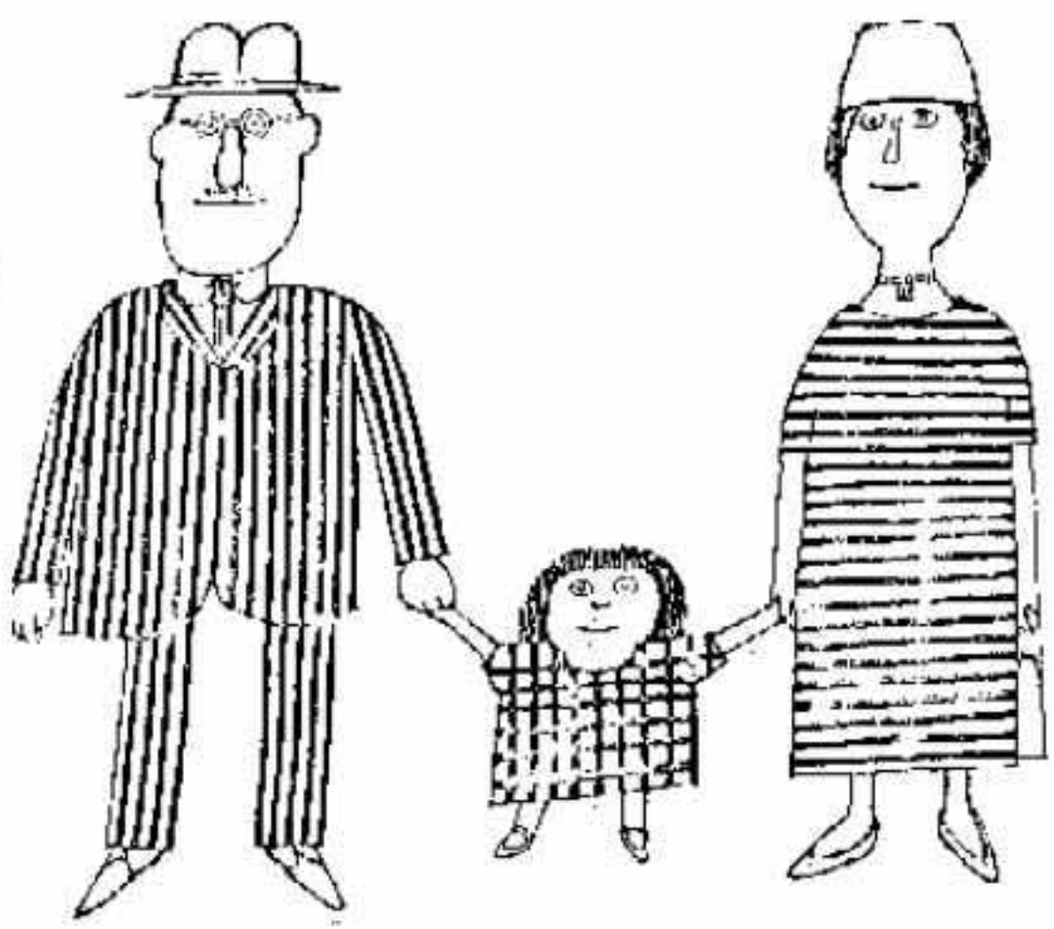
Many social, anxiety and aggression traits that are strongly influenced by parental care in animals

Other epigenetic effects?

Many social, anxiety and aggression traits that are strongly influenced by parental care in animals

So parents may alter the life-long social behaviour of their offspring through promoting epigenetic changes

A sobering thought perhaps for both parents and children



The future of human social behaviour?

Social behaviour is highly flexible and vulnerable to mutation and cultural change

The future of human social behaviour?

There are many genetic disorders that impact on aspects of sociability

The future of human social behaviour?

Many species can switch between social and asocial phenotypes by changing a single gene

The future of human social behaviour?

If we adopt a progressively asocial lifestyle it could quickly become an inherited trait

The future of human social behaviour?

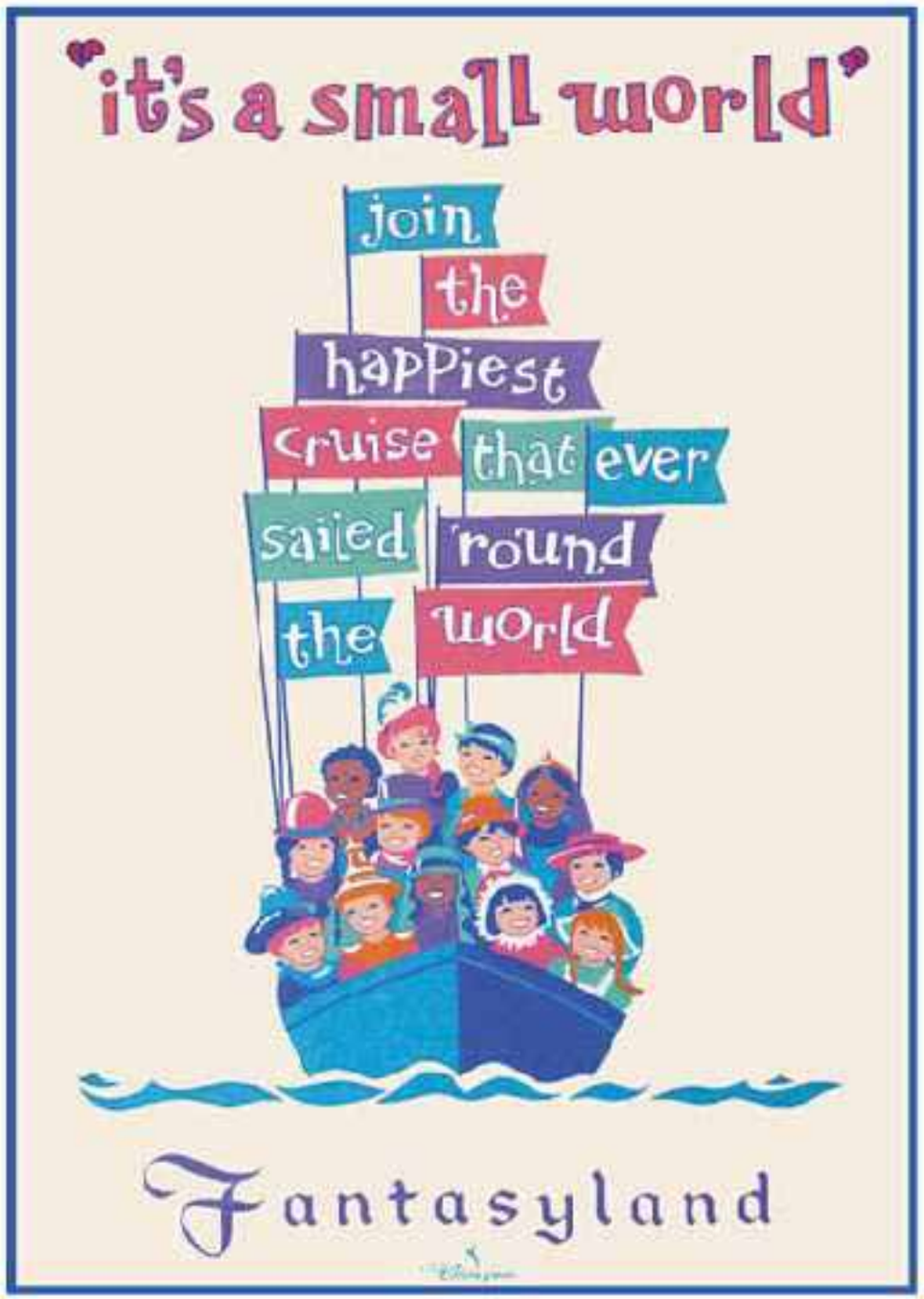
Anti-social behaviour patterns are on the increase and pro-social ones on the decrease

The future of human social behaviour?

Are we moving towards individual rather than societal based cultures?

The future of human social behaviour?

Family, local, national and global boundaries are becoming blurred and resources easier to obtain



The future of human social behaviour?

Co-operation is more about joining forces for resource acquisition than for reproductive support

The future of human social behaviour?

Social altruism is an expensive form of co-operation!

Some final conclusions

Social behaviours improve reproductive fitness...

...and are under strong genetic control

Even co-operation and altruism have genetic components

Both genetic and epigenetic mechanisms are involved

Some final conclusions

Parental influences play a key role in epigenetic effects

Touch during early social interactions may be important

Single gene deletions and polymorphisms can have major effects

Some final conclusions

There are many human genetic disorders with altered social behaviour

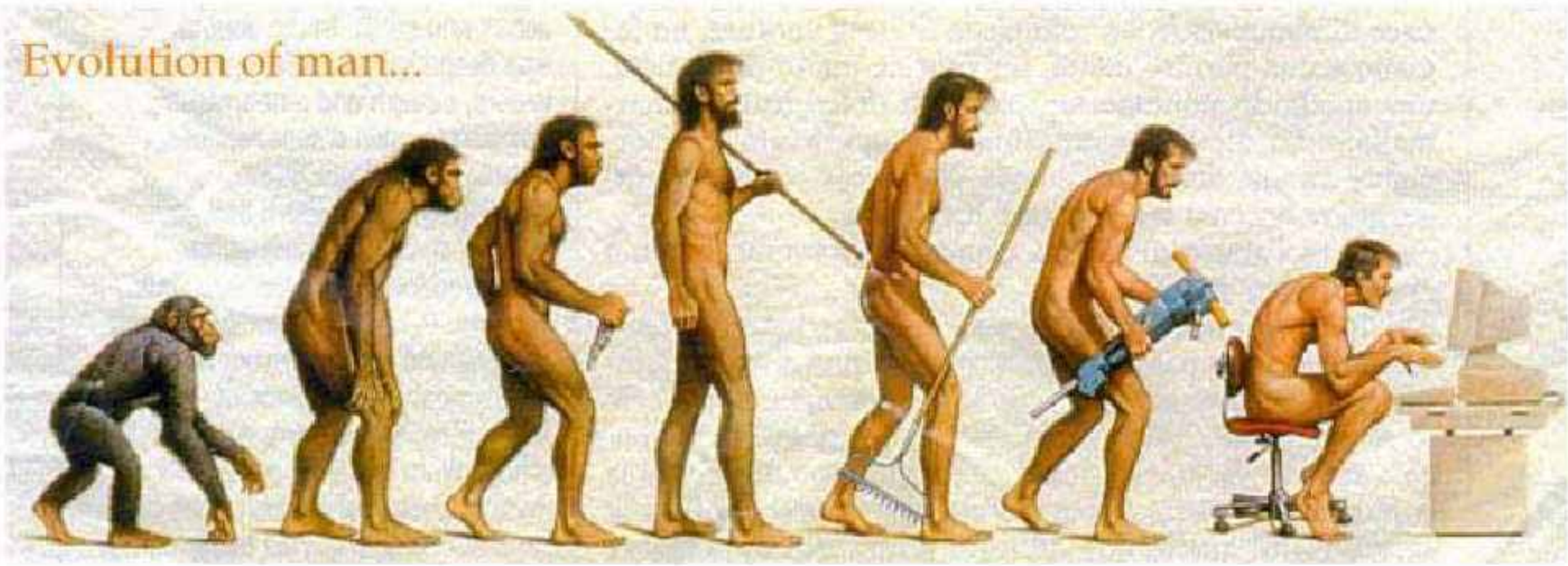
Many other species can switch from being asocial to social

Some final conclusions

It would be relatively easy for humans to evolve into an asocial species...

Some final conclusions

It would be relatively easy for humans to evolve into an asocial species...



...or has it already happened?