The left, right and centre of male and female brain politics

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One of the greatest puzzles for neuroscientists has been the functional importance of having two brain hemispheres. On the face of it this seems a strange way to arrange integrated control of detection of things in our environment using our different senses and control over the movement of the right and left sides of our body, let alone our cognitive and emotional faculties. The advantage of having two central processor units in a computer is primarily additive although they can be used to process different sets of information. So are the left and right sides of our brains simply involved in some kind or additive processing or are they involved in doing different, albeit complementary, things? And are the ways that the two different brain hemispheres process information somehow fundamentally different in males and females and in a way that can easily explain the behavioural sex differences we can observe quite readily in our every day lives?

The Evolution of two brains in one.

If you really wanted your right hand to know what the left was doing then surely it would make sense to have them controlled by a single brain processor. Similarly, if you really wanted to integrate sights or sounds occurring on the left side of your body with those occurring simultaneously on your right side it might seem to make sense to have the sensory information from both sides processed by a single processor. But in point of fact these kinds of information are initially processed separately in the right and left brain hemispheres. Our two brain hemispheres are also capable of independent consciousness although, as we will see later, selectively and reversibly inactivating one at a time reveals rather different access to information and specific faculties such as language. You might say this is all analogous to the kinds of relationships which exist between the political parties sitting on the different sides of the House of Commons!! But one might not want to press the analogy too far in this case!

In essence the obvious advantage of having two independent information processors in the brain is that it provides options for both parallel and independent analysis and control of function. Or put another way you can really do two things at once without them interfering with each other or you can combine forces. Another advantage is that having some information represented independently in the two brain hemispheres both allows reduced susceptibility to dysfunction and the separate integration of that information with different specialised processes that are more localised in one particular hemisphere.

So the left and right brains have considerable options at their disposal for how information is processed and behaviour controlled. But the two sides must obviously benefit potentially from exchanging information and from engaging in “joined up thinking”. There are therefore extensive wiring connections in the centre of the brain between the two brain hemisphere – 200 million fibres alone in the main fibre tract between them, called the corpus callosum.

But this brief analysis of how things are with a two brains in one scenario does not immediately explain why this way of doing things has evolved in animals. After all, you could make the argument that a single brain processor might reduce apparent redundancy of having to have information duplicated in both hemispheres and the resultant smaller brain would require far less energy to maintain – or perhaps more computational power could have been made available in a similar sized brain to the one we have at present but where there is only one processor.

So what could the real adaptive advantage be of having two brains? Whatever it is, it must be of fundamental importance to survival because all animal species with a brain use this design.

Despite the obvious observation that the principle of animal design states that everything on the side of a body comes in twos and everything down the centre in ones, even the single features of the body have two sides and are represented on separate sides of the brain. So is that it, because it makes sense for an animal body to be designed with two of everything, or two sides of everything, the brain has to have two sides as well? – i.e. it is optimal bilateral body design for walking, manipulating objects or sensing information arriving from either side of the body. This seems reasonable on the face of it, but when one considers that these paired structures in our body tend to do things in a co-ordinated manner, rather than independently, it does beg the question as to why they are not controlled in a more uni-representational manner.

The key to answering the question "why two brains rather than one?" lies in considering what the two sides do that is actually different from one another. While it may be tempting to focus entirely on language to consider this issue, due to its strong lateralisation within the left brain hemisphere in humans, this is something that has evolved comparatively recently and may simply have taken advantage of organisational principles that had already evolved millions of years previously for a much more fundamental purpose.

Up until comparatively recently it was widely thought that lateralised functions in the brain were yet another example of a unique facet of human evolution, but it is now clear that they are quite common and present even in the most primitive species such as fish, amphibians and reptiles (see Rogers and Andrew, 2002). From observations made in large numbers of these species it does indeed seem parsimonious to conclude that brain asymmetries have evolved primarily to separate out information that may lead to conflicting behavioural and emotional responses i.e. you don't want to approach a predator and you don't, hopefully, want to run away from a prospective mate!

Examples of common functional brain asymmetries

The simplest forms of functional asymmetries are turning and sensory biases. Here individuals may develop strategies where they are more likely to turn or jump one way to threatening stimuli for example. These may either be the result of biases in motor control systems per se or additionally/alternatively in terms of sensory information from one side being better or more likely to evoke a particular set of responses by gaining access to a brain hemisphere specialised for controlling appropriate evasion responses. Many of these examples across the animal kingdom suggest that information routed to the right brain hemisphere results in a quicker more effective response to threatening stimuli and for eliciting sexual and aggressive responses. The right brain hemisphere also seems to more effective for social recognition and using visuospatial information for solving problems. By contrast the left hemisphere seems specialised for the production and interpretation of vocal communication in many birds and mammals, including of course speech and word recognition in humans. There is also some suggestion it is involved in promoting approach towards and manipulation of attractive identified objects such as food and that it is generally important for emotional control and interpretation, particularly in social contexts.

General gross structural asymmetries in the human brain

Even a quick glance at a human brain will reveal that the two sides are not quite the same shape and proportion. In what has been termed a Yakolevian anticlockwise torque the right frontal lobe extends across the midline, over the left, and the left occipital lobe (at the back) protrudes over the right giving the appearance of a twisting force. The other major difference, called Petalia, and evidenced by the impressions seen in skulls is that the right frontal lobe extends beyond the left at the front of the brain and the left occipital cortex beyond the right at the back. One of the major fissures of the cortex, the Sylvian fissure also runs a different course on the two sides of the brain. However, overall there are now a wide range of other structural differences identified in the two brain hemispheres and particularly in those regions involved in language within the left hemisphere (see Toga and Thompson, 2003).

Handedness

While handedness is one of the most obvious examples of functional asymmetries in humans and at the population level the majority of individuals are right handed (90%) there are also extensive examples of limb preferences in other mammalian species and also in birds where not only is there a paw or foot preference but this also shows a significant bias towards the right side – which is controlled by the left brain hemisphere. The right bias is generally less pronounced in other species though and is of the order of 60-70%. Surprisingly though handedness is not particularly associated with large differences in the parts of the motor cortex of the brain representing the left and right hands, although there are some microstructural changes. A neurochemical factor that may bias right-handedness is that the levels of the neurotransmitter dop ami ne, which is important in parts of the brain controlling motor activity, are higher in the left brain hemisphere than in the right. This may also help to explain why language production – which is also a motor task – has been localised in this same hemisphere.

Language

The presence of specialised regions in the left brain hemisphere for production of speech and language recognition were the earliest discovered of human brain asymmetries by Broca in 1861 and Wernicke in 1874. Since that time many other regions have been identified within the left brain hemisphere involved with different aspects of language comprehension, one of the major ones often referred to is the planum temporale. Language is not always located in the left hemisphere though and is associated with handedness. Thus, 97% of right handers have language control localised in the left hemisphere compared with only 3% in the right. By comparison with left handers only 70% have it localised in the left hemisphere and 30% in the right. Genetic, experiential, developmental event and hemispherical differences in neurochemical concentrations may contribute to this.

Not surprisingly, the sizes of the areas dealing with language on the left side of the brain are significantly greater than equivalent regions on the right. Control of song production and recognition in birds and vocalisations in mammals also has a left brain hemisphere bias. Interestingly, chimpanzees have a larger planum temporale in their left hemisphere even though they don’t have language. This indicates that these specialisations predated the evolution of language and may perhaps have supported other non-verbal forms of communication, such as gestures for example.

Social recognition, cognition and emotion

There are extensive claims supporting differential roles for the two brain hemispheres in controlling social recognition, cognition and emotion but I will confine myself to a discussion of just a few of them.

Social recognition

Recognition of faces and face emotion is very much a right hemisphere dominated task in humans and we have shown that this is also the case in other mammals such as sheep. Because of the crossed nature of the visual projection system information from the left visual field is preferentially processed by the right brain hemisphere. In both humans and sheep therefore the visual cues from the left side of the face are utilised more accurately for recognition than those from the right.

With face emotion recognition this is true as well with the right amygdala being more strongly activated by fearful and anxious faces than the left. For, humans, chimpanzees and sheep there is also evidence that cues from the half of the face in the left visual field are more important than those from the right. Indeed, there is evidence that most humans have also developed asymmetrical facial expressions with changes on the right side of the face (i.e. the left visual field for an observer) being greater than those on the left (right visual field).

Vocal recognition of individuals and vocal emotion processing are also primarily localised in the right brain hemisphere.

Social recognition in rodents and sheep using smell cues has so far not been shown to involve one hemisphere more than the other, but this is perhaps not that surprising given that diffuse odour cues tend to processed by both nostrils simultaneously. Smell, unlike vision and hearing, is also an ipsilateral projection system (right nostril to right brain hemisphere) and involves less brain cortical processing than the other recognition senses.

Cognition and emotion

Over the years the broad concept of an “intellectual” left brain hemisphere and an “emotional” right one has received varying degrees of support. More recently though the left brain hemisphere has been considered to perhaps have importance for positive emotions with the right more involved with negative ones. In particular, the left frontal cortex has often been reported to be activated by positive emotional stimuli and the right by negative ones, although the right amygdala seems to be activated by any form of intense emotion, but particularly fear. However, it is clear that such a simplistic interpretation of what the two hemispheres are doing is misleading.

Studies on recognition of face emotion suggest a more integrated view of how the right and left hemispheres may work for all emotions. They suggest that perception of intense face emotions such as fear require the right amygdala to evoke autonomic arousal changes whereas the left amygdala is more important for better cognitive judgments of just what exact emotion is being expressed by the face. Furthermore, if the right amygdala is activated it actually facilitates performance by the left amygdala in identifying what kind of face emotion is being expressed. Also, in the absence of a functional left amygdala, individuals have more problems controlling the arousal consequences of being exposed to fearful faces. So we end up with a situation where activation of right hemisphere fast reaction emotional systems primes the slower more considered cognitive left hemisphere ones which can in turn modify the current and subsequent responses on the right.

This complex interaction between the hemispheres for controlling emotional responses implies that the presence of connections between the two hemispheres is important for appropriate expression and control of emotional behaviour. Indeed, studies of individuals with degeneration of such connections have confirmed this. The other implication, of course, is that better connections mean better control and I will come back to this later when discussing gender differences.

This idea of cooperative, complimentary emotion processing by the two hemispheres with the right involved in a rapid response, relatively undiscriminating role and the left in a more considered, integrational and override one can easily account for the wide differences in activation patterns reported in brain imaging experiments. This model predicts considerable contextual and temporal influences on whether changes are seen in the right or left or both hemispheres. It is worth remarking in this context that with face recognition and face emotion stimuli in both humans and sheep the speed of left hemisphere responses is slower than those in the right which further supports this more considered role I am claiming for the left.

With learning and memory the roles of the two hemispheres once again seem to be broadly complementary with the lead roles taken by individual brain hemispheres being dictated by the kind of information being learned - for example, verbal on the left and visuospatial on the right. Even in rats it has been shown that if they learn to negotiate a maze using visual cues they can perform the task with information that can only access the right hemisphere, but not if it can only access the left.

Experiments in humans which deliberately present information so that it accesses one hemisphere or the other (presenting information briefly in either the left or right visual fields or to the left or right ear or even conflicting information on each side), or where one hemisphere is temporarily anaesthetised, or where the fibre connections between the two sides of the brain have been cut – “split brain”, can also illustrate almost bizarre levels of information being stored, or accessible to, only by one hemisphere with the other apparently ignorant of what its counterpart knows – or even having a different set of information available. With split brain patients for example viewing a chimeric face with a woman on the left side and a man on the right will identify it as a woman if they are asked to make a response by chosing from a set of face pictures (i.e. right hemisphere dominant) but as a man if the response required is verbal – i.e. is it a woman or a man? – language being left hemisphere dominant. However, in other instances it is clear that both hemispheres have the learned information but are limited in what kind of response that they can execute in response to it.

It is also clear that both brain hemispheres are independently capable of generating a state of consciousness, although the content of that consciousness reflects the respective specialisations of the two hemispheres – the left more verbal and the right more visual for example. Even so those individuals with no or impoverished connections between the two brain hemispheres are not as disadvantaged as one might think cognitively and do not report having separate conscious experiences of the world. This is mainly because real life information is rarely received in such a way that both brain hemispheres don’t receive it simultaneously. The integrative link between the experiences of the two hemispheres can therefore be externally generated even if the internal links don’t exist.

The impact of experience

The extent to which brains become functionally lateralised may be influenced significantly by experiences throughout life.

Early life experience

While there do not seem to be that many studies that have investigated the impact of early life experiences on lateralisation of brain processing in humans there have been some interesting observations reported recently in rodents. Asymmetric exposure to sensory stimulation or compensation for unilateral hemisphere brain damage can, unsuprisingly, lead to structural changes in specific hemispheres. However, less obvious is that neonatal handling and prenatal stress can also do this. Just handling rats for 10 min every day for the first three weeks of their life produces an increased size of the right hippocampus and its role in memory and responsivity to stress hormones (see Tang in Hugdahl and Davidson, 2003).

The ageing brain

Advances in brain imaging techniques have revealed striking differences in the way young and old brains process new learning tasks (see Reuter-Lorenz, 2002). Two general findings are that old brains seem to process new information both using more of the brain and with a reduced amount of specialised use of one brain hemisphere as opposed to the other. For example, initial work found that for matching faces and locations young adults showed a restricted activation of ventral parts of the temporal lobe for faces and the dorsal parietal lobe for locations. Older individuals showed equivalent activation of both brain regions in both tasks.

With verbal working memory tasks (short-term memory for lists of words) other studies have shown that young adults only activate a subset of brain regions within the left hemisphere whereas older ones activated the same regions on both sides of the brain and also involved additional parts of the prefrontal cortex that were less activated in the younger group.

So old brains do things differently from young ones: why? Two general possibilities are that either old brains have to compensate for loss of power by engaging more systems to help out, or that ageing breaks down the brain's ability to use its optimal specialisation strategies of lateralised processing. These two possibilities are not entirely mutually exclusive and probably both are going on. However, a recent study has provided some support for the compensation hypothesis.

Cabeza et al (2002) found that in similar word-based memory tasks, older people who were assessed to be low-performers on most cognitive tasks (i.e. had undergone some age-associated cognitive decline) showed similar lateralised and restricted patterns of activation within the frontal cortex as found in younger individuals and their memory performance was worse. On the other hand, high performing older individuals showed a bilateral and wider activation pattern within the frontal cortex but had a similar memory performance to the young ones.

This may also go some way to explain why older individuals are generally slower in performing these cognitive tasks than younger ones because one of the advantages of using restricted and lateralised brain systems for information processing is that they allow you to do things faster. So perhaps the bottom line is that if you want to hang on to your cognitive powers when you get older you will need to use more of your brain and this may slow you down a little!

Why some individuals retain youthful restricted patterns of brain activation and may as a result become cognitively impaired as they get older is an important question. The most likely explanation is that your ability to compensate for the effects of age by using your brain in a different way comes back to the "use it our lose it" scenario. It you constantly challenge your brain to deal with demanding problems then it will become more flexible and able therefore to adapt to age-related changes. If this is true of course it means that the degree to which lateralisation of function is utlised by individual brains is modifable by experience and not hard wired. However, as we will see in a minute, this raises some interesting questions about the nature of laterisation differences that seem to be present in male and female brains.

Sex/Gender differences in the brain

We all know of course that males and females of all species are different and in humans this has led to some extreme popularist views being expounded along the lines that we are so different we could have come from different planets (i.e. "Men are from Mars and Women are from Venus" – Gray, 1993) or are just are not cut out to do the same things (Why Men don't Iron – Moir and Moir 2000). Some would even go as far as to suggest that if there was not the powerful biological imperative of mutual sexual attraction, men and women would form separate societies and have little to do with each other. However, there is a large amount of pseudoscience and exaggeration at the back of much of these extreme views and perhaps pandering to deep seated convictions that men don't understand women and vice versa. It is important therefore to try and separate truth from fiction and perhaps most crucially to state up front that in the vast majority of cases cognitive and emotional differences between the sexes are not generally as large as people often claim and that variation in any particular skill or trait within a sex is normally greater than between them. Indeed, one important take home message is that not all males have male-type brains and not all females have female-type brains. At the brain level distinctions between the two sexes are far less straight forward than determining sex by appearance and the presence of appropriate sex organs.

If you read the literature on this subject the study of differences between the sexes often distinguishes between sex differences and sexual dimorphisms to indicate hard-wired biological differences and "gender differences" which refer more to more experientially derived changes. For a long period of time a debate has raged between factions who claim that there are only gender differences (i.e. it is all down to the different environments and expectations the two sexes experience in society) or that differences have primarily a biological basis resulting from genetic and hormonal influences and that gender role expectations play little or no part at all. It is often difficult to disentangle these two possibilities other than in highly controlled animal studies. However, I think it fair to state from the outset that the growing evidence we now have of failure to alter individuals sexual identity and orientation through experience and the robust presence of some sex behavioural sex differences virtually from birth make it clear that the "its all down to differential cultural expectations and experiences of the two sexes" view is completely untenable. This is not to say however that cultural and experiential factors are of no importance.

Sexual reproduction and orientation

It is now widely accepted that the default sex is female and that it is the presence of genes on the Y-chromosome that cause the development of testes instead of ovaries, male genitalia and a male brain and sexual orientation as a result of testosterone production. The organisational effects of testosterone on the brain occur both in utero and during the period immediately after birth when levels are high and also again at puberty. It is relatively easy to dissociate the presence of male or female reproductive organs from male and female sexual identify and orientation however. This seems to be because hormonal effects on brain organisation occur over a longer time period and so in animals such as rats removal of testosterone by castration immediately after birth will allow males to show female endocrine and sexual responses after oestrogen treatment in adulthood even though they are genetic males with male sex organs. Similarly, females treated with testosterone during this period will show a male sexual response but be genetic females with female genitalia and organs.

Just what changes have occurred in the brain as a result of testosterone exposure have not been so easy to demonstrate however. There are some sexually dimorphic regions in the main part of the brain involved in the control of sexual behaviour and pituitary hormone release, the hypothalamus, in both humans and some other mammals. Generally the finding is that some specific brain nuclei are larger in males than in females although the precise functional significance is not that clear. Indeed it seems likely that the main differences between male and female brains that control their different sexual responses and orientation reside in how they are wired-up and release and respond to different chemical transmitters.

What about a homosexual orientation? LeVay and Hamer (1991) found that the sizes of some hypothal ami c regions in gay men more closely resembled those of women than heterosexual males. Some endocrine responses to sex hormones also more closely resemble those of females than heterosexual males. Largely based on observations in animals it is now widely assumed that the brain differences that cause a homosexual sexual orientation are present from birth and as a result of altered sex hormone levels during foetal development. In general factors which suppress testosterone during the perinatal period, such as high levels of stress during pregnancy, have been associated with a higher incidence of homosexuality in offspring although these effects remain controversial. Genetic factors may also be of importance. However, it is clear that hormonal changes during puberty do not influence sexual orientation although they do infuence subsequent levels of libido and sexual arousal.

The best documented example of homosexuality in another species with close parallels to humans is the sheep. Approximately 2% of male sheep show exclusive male sexual orientation - this compares with 2-6% in humans. There is also a very similar pattern of brain and endocrine differences in 'gay' sheep as those seen in human male homosexuals.

Romantic love

While there are clearly important differences in the brain that determine both sexual identity and orientation the issue as to whether the fundamental nature of attraction, sexual arousal, love and bonding with a partner is different in males from females is more difficult to ascertain. The most established differences between the sexes in humans are that males are more attracted by visual features in females (baby faces, symmetrical features, skin quality, body shape – 0.7 waist to hip ratio, size of breasts etc) and fall in love more quickly. Females on the other hand may like tight butts and other visual features but are more interested in weighing up the total package by taking far more factors into account – including resource provision! An intriguing although unexplained difference is that females are more likely to report feeling “lighter than air” when in the intense phase of romantic love than males are.

Brain imaging studies in humans have not year reported fundamental significant sex differences in either the regions activated or inhibited while viewing face pictures of romantic partners although there has been a preliminary report that in women areas of the brain involved in memory might be more strongly activated. In both sexes there seems to be strong activation of areas of the brain associated with pleasure and reward and containing the neurotransmitter, dop ami ne. Similarly, there seems to be equivalent activation of these pleasure areas of the brain during male ejaculation and female orgasm – although not when the latter is faked!

One potential area of difference that may also be relevant to humans has been the discovery from different species of voles that are either monogamous or promiscuous that sex and partnering in monogamous females are associated with activity of the peptide hormone oxytocin, whereas in their male counterparts another different but related hormone is involved, vasopressin. In monogamous species both of these peptides are able to release dop ami ne within pleasure/reward centres in the brain. In the human female oxytocin is also released during orgasm. There must be some difference in the ways the male and female vole brains are organised though because oxytocin does not promote partner bonding in males and vasopressin does not in females.

Whether oxytocin and vasopressin are differentially involved in male and female romantic love and bonding in humans is not yet known with brain imaging studies showing that areas of the brain containing receptors for both peptides being similarly activated in both sexes when viewing pictures of romantic partners.

Parenting and offspring bonds

One of the most obvious sex differences in animals, particularly mammals is parenting. Only in the 3-4% of monogamous mammalian species do fathers get involved in parenting at all. In those species, including humans of course, where fathers do become involved in raising the kids there is clear evidence that hormonal changes occur which make them more like females than males – or at least perhaps get in touch with their more feminine side. These changes include decreased production of testosterone and more of oestrogen, and increased production of the hormone prolactin which, amongst other things, stimulates production of breast milk. Fathers in some species, notably the fruit bat, can actually produce milk!

However, again a major apparent sex difference, at least in voles, is that oxytocin controls maternal behaviour and bonding whereas it may well be vasopressin that controls paternal behaviour and bonding.

The influence that parents have on their male and female offspring does, at least in animals, show support for the idea that mothers are more influential on their sons than their daughters. In cross-fostering studies we have carried out and sheep and goats we found that mothers had a much stronger and apparently irreversible effect on the development of social and sexual preferences in males than in females. Females appeared quite capable of changing their preferences in the light of new social experiences whereas males were not. Similar sex differences have been reported in birds. In sheep and goats we have shown that this apparent sex difference is likely to be caused by prenatal organisational effects of testosterone on the male brain rather then, for example, the presence of stronger bonds between mothers and their male offspring (Kendrick et al, 2000). So experience of early emotional bonds may have greater long-lasting effects on males than females. This suggests that the female brain may have more flexibility in integrating emotional experiences than the male one. Whether this is true of humans is clearly much less easy to demonstrate although lies at the heart of Freud’s concept of the Oedipus complex.

Sensory perception and attention

In general if there are any advantages in terms of detection of sensory signals from the environment then it is females who have them. Very often the peaks of their sensitivity occur at mid-cycle when oestrogen levels are highest although advantages are not normally totally dependent upon this.

Smell and taste

The best documented advantage is that for detecting smells which also ends up confering increased taste sensitivity as well. With the latter females have better detection of sweet, sour, salty and bitter substances. With smell females have a general advantage but particularly with my biological odours of relevance to the context of males. One of the adaptive advantages of this may be to better help females identify appropriate mates since odours can be used to identify the immune complexes of partners and the general strategy is to avoid pairing up with individuals who have the same immune complex as yourself.

Interestingly for the musk smell incorporated into many female perfumes, females may have 1000 times more sensitivity for this than males and so a female wearing such a perfume is more likely to attract another female than a male!

Touch

Females are more sensitive to touch in virtually all regions of the body with the vagina being the most sensitive of all.

Hearing

Females have been shown to detect sounds slightly better across the frequency spectrum using a test of their abilities to detect pure tones. They also have a particular advantage at frequencies above 4KHz.

Vision

Females also have slightly better visual acuity than males which presumably also helps with their advantage in fine motor tasks. However, males are better at detecting movement using peripheral vision which may have conferred advantages for hunting in the past as well as a better early warning system to detect an attacker.

Attention

To some extent here males have both the best and the worst skills. Focussed attention on a particular task is something that males do well at and has been shown to be influenced by the male sex hormone testosterone. Females on the other hand excel more at multitasking divided attention tasks. However deficits in attentional function are far more frequent in males than females, notably in terms of the incidence of attention deficit hyperactivity disorder (ADHD).

Play

Sex differences in play behaviour are even slightly greater than those for height! Even by the end of the first year of life boys and girls prefer different toys. These persist throughout the remainder of childhood. Boys are more into cars, trucks and guns, whereas girls go more for dolls and tea-sets etc. Boys also engage in more rough and tumble play, including play-fighting and wrestling, than girls. Also boys and girls mainly chose playmates of their own sex (80-90%). While it has often been proposed that much of this is due to cultural gender expectations in humans rather than to some biological sex difference it is clear that biology is playing a large role. With other mammals there is a similar clear-cut sex difference in rough and tumble play that is associated with prenatal exposure to testosterone. This importance of prenatal testosterone is also clear in humans with various congenital hormonal abnormalities where either girls are exposed to high levels of testosterone (congenital adrenal hyperplasia - CAH) or boys are unable to respond to their own testosterone (androgen insensitivity syndrome – AIS). Studies have also shown a good correlation between levels of testosterone in amniotic fluid (taken during amniocentesis) and male type play patterns (see Baron-Cohen, 2004).

What about sex differences in toy preferences though? You might perhaps think that boys prefer cars and trucks because they see them every day in their world and are encouraged to play with them as a feature of cultural gender expectations. If this were the case then you might not predict effects of early hormonal abnormalities involving testosterone exposure. However, such abnormalities do also have significant effects. Even more convincing perhaps is that male and female vervet monkeys show exactly the same sex differences in playing with these human toys! (see Hines, 2004).

While it is perhaps easy to postulate that doll play in girls is associated with their greater interest in social interactions, playing with cars and trucks by boys and male monkeys is a little more difficult to explain. Perhaps they are just highly appealing to interests in action and movement and functional investigation of objects that are more motivating for males than females.

Aggression

While aggression is often cited as one of the strongest sex differences this is by no means as clear cut as it might appear and very dependent upon context. Levels of aggression do not correlate that closely with absolute levels of the male sex hormone testosterone either. In terms of violent crimes males do have a significant leading role and there are generally higher levels of inter-male aggression than there are of inter-female aggression. However, in other contexts such as defending young, females can be more aggressive than males. One also has to make distinctions between physical and psychological aggression with males more likely to engage in the former and females in the latter. Clearly differences in body and muscle sizes in the two sexes have an impact on the aggressive strategy used.

Intelligence, language, cognition and emotion

This is always the most contentious area of debate when comparing the sexes and once again it is important to emphasise that reported differences are usually very small and rarely do all studies agree with one another. The important take home message is that male and female brains function slightly differently in dealing with information and integrating and expressing emotional cues and that neither the male way nor the female way of doing things is necessarily better.

General intelligence

Females generally have smaller brains than males even when taking body size into account (1442 cm 3 for males and 1332 cm 3) although the evidence that this is associated with reduced intelligence – at least as measured by IQ tests – is somewhat inconsistent. In the majority of cases men end up with a slight IQ advantage of between 2 and 8 points whereas women do better on short-term memory at about the same level. Probably the most consistent finding is that IQ is more variable in males then females which roughly equates to the conclusion that there are more males at the highest and lowest ends of the IQ spectrum than there are females. Or put another way, as a female colleague of mine put it succinctly to me, there are proportionately more males than females who are either idiots or geniuses! Women are more balanced and consistent intellectually perhaps than men!

There are apparently some sex differences in general knowledge ability though. Rolfhus and Ackerman (1999) found that males outperformed females in history, politics, geography and science while females were superior in art. Lynn and Irwing (2002) found in a study of 1047 undergraduates that males performed better in knowledge of sport, science, affairs, geography, politics and history while females were better on medicine and cookery. However, on the other 60-75% of areas tested there were no sex differences.

A recent structural brain imaging study has shown striking sex differences in brain regions associated with general intelligence (as measured by the Weschler Adult Intelligence Scale – WAIS). It looked at different gray (nerve cells) and white (nerve fibers) matter contributions in the two sexes. Firstly they found that for gray matter men's IQ was correlated with higher volumes of the frontal and parietal lobes whereas in women this was the frontal lobes and Broca's area. The frontal lobes are important for memory, consciousness, self-awareness, processing social cues, moral judgements, emotional and response control and link strongly with pleasure and motor control systems. The parietal lobe is important for spatial awareness and judgements and Broca's area for speech and also for aspects of imitation which may underly empathy. So in crude terms intelligence may be more associated with verbal and imitation skills in women and spatial ones in men - a basic theme that is often proposed. However, the other main difference between the sexes was that there were also more extensive correlations with white matter in females than in males and the opposite for gray matter. I will return to this latter but this suggests that for the female brain transmission and integration of information across brain regions is more important than in the male brain.

Language and verbal abilities

In a review by Maccoby and Jacklin (1974) they concluded that during pre-school and early school years, girls do better than boys in most aspects of verbal performance including:

- Saying their first word earlier
- Articulating more clearly at an earlier age
- Using longer sentences
- Greater fluency
- Learning to read sooner
- Better performance on tests of grammar, spelling and word fluency.

To some extent these advantages may reflect an earlier maturation rate in females but may also be contributed to by differential treatment of boys and girls by their parents. It seems that mothers talk more with girl babies and encourage social interaction while encouraging boy babies more towards some form of achievement or positive action. This was shown to be the case even using other people's babies where the same child was either dressed as a boy or a girl!!

However, while these early advantages are robust in adulthood the differences in language and verbal skills between the sexes are relatively small. Hyde and Lin (1988) in a meta-analysis of 165 studies concluded that females had advantages on verbal fluency and memory and males on verbal analogies.

Cognition and emotion

There are a number of types of problem solving tasks where there are significant sex differences.

Males better than females:

Spatial orientation/mental rotation – making a correction for a change in the orientation of an object (i.e. being able to rotate it mentally to assess how it should appear from a different viewpoint). Ask a male for directions and you will be more likely to be told go North or turn left after a couple of miles.

Visualization – determining how an object will appear when it has been manipulated in some way such as folding. This is sometimes referred to as mental rotation, being able to visualise in your mind how objects will look from another angle or transformed in some way.

Line orientation – matching the slope of a line.

Mathematical reasoning - solving a novel mathematical problem. It is this advantage that seems to be responsible for keeping males at the top of academic and industry areas involving application of mathematics. The gap between males and females on SAT-M scores is not diminishing and so this is not just a cultural matter.

Throwing accuracy – hitting a distant target with some form of projectile. Very useful of course for hunting in the past.

Females better than males:

Object location memory – remembering the locations of objects. Women realise very quickly when something is out of place. If you ask a woman for directions you are more likely to receive instructions based on specific landmarks rather than more generic instructions such as go north etc.

Perceptual speed – tasks that require matching of objects. Females are better at making judgements that pairs of objects are the same or different – good for playing "snap" perhaps but also good for routine tasks which require finding a large number of similar objects (when foraging for specific foods or resources in the environment which women would have done in hunter-gatherer societies. This is perhaps why women are good at quality control in production lines!

Verbal memory – recall of any materials containing words.

Numerical calculations – routine application of learned calculation skills. This can of course give females some advantages with accuracy in maths tests where one is instructed to apply a particular rule rather than having to decide how to formulate a novel problem and then pick what rule to apply.

Dexterity/fine motor control – any tasks that involve fine manipulation control and dexterity.

As far as sex differences in emotional behaviour and control are concerned then evidence suggests that while emotional experience is probably similar, females are more emotionally expressive. Females are more likely to show facial expressions of emotion than men. This is particularly the case with smiling but is also true of sadness, disgust, fear and surprise. This forms the basis of the claim that women are better at communicating their emotions than men!

It is perhaps easy to speculate from all of this why relatively few women make it to the top of their chosen professions. There are, of course, many cultural and domestic factors that can contribute but it is easy to generalise that from the above description of sex differences females should always make the better, reliable, appliers and team players whereas some males should be more focussed, innovative and ruthless in achieving their aims and make it to the top, whereas at the other end of the spectrum just as many should be useless in this respect. It is even easier to see however how the two sexes should complement one another in the work place – or in any other context!!

Female empathic, web-thinking, distributed, bilateral brain vs Male systematised step-thinking, localised, lateralised brain

A recurrent claim made by researchers on the basis of an extensive literature on differential effects of brain damage in the two sexes, brain imaging and structural studies and assessments of behavioural of cognitive and emotional functioning is that the female brain is less lateralised than the male one. The advantages for the female brain being better social and emotional integration and control, easier multi-tasking and reduced susceptibility to problems following localised brain damage. The male brain on the other hand may be better suited to focussed attention on tasks, fast specialised problem solving and keeping emotional and cognitive domains from getting too much in the way of each other!

This has led to some interesting ideas which try and encapsulate the fundamental differences between a male and female type brain bearing in mind, once again, that most recognise it is possible to have males who have more female type brains and vice versa.

Helen Fisher in her book "The First Sex", and subsequently, has described females as "web thinkers" which captures well the idea of a multi-functioning more integrated brain where everything is linked up with everything else. Simon Baron-Cohen in his book "The Essential Difference" describes the female brain as more "empathic" which again captures the idea of a more sophisticated and integrated emotional intelligence that underpins more effective social interaction. Males are described more as being "concrete" and "systematisers", befitting the idea of more interest in operational rather than social and emotional matters. Simon Baron-Cohen considers that it is the most extreme form of male brain where it only systematises and has little, if any, emotional intelligence is akin to developmental conditions, such as autism and aspergers, where emotional communication and interpretation is often severely impaired but in some cases individuals can have remarkable skills in problem solving, drawing etc. Both these conditions are of course far more prevalent in males than females.

So why might female and male brains be so different?

The simplest explanation for this is to evoke adaptation to very different challenges and environments for male and female humans that may possibly apply to other species as well. With humans males in hunter-gatherer adaptations spent most of their time travelling long distances and hunting and so needed good skill sets for general direction sense and hunting but perhaps fewer social skills. Females on the other hand remained close to home and could therefore negotiate their environment using familiar landmarks and required better social skills both for nurturing infants and for cooperation and communication with other females to help with nurturing, food gathering and preparation and domestic responsibilities. Females also tended to deal with domestic tasks requiring fine motor control. While it is difficult to make these kinds of arguments with all other mammals, females are generally far more involved in nurturing males and males with defending wide territories. Indeed, in voles the degree of male right hemisphere lateralisation has been associated with the respective range sizes covered by the males of different species – the wider the range the more lateralisation.

How do you know if you have got a male or a female type brain?

Of course one can just conduct a barrage of problem solving and emotional intelligence tests where females and males differ in performance. However a simpler way is to measure whether the parts of your body are larger on one side than another. Males with typical right brain hemisphere dominance tend to have a larger testis on the right and females with a left brain hemisphere dominance tend to have a larger left breast and ovary. Of course measurements of this tend to rely on self-report since not even Psychologists can easily get away with fondling breasts or testicles in the name of science. However, Doreen Kimura "Sex and cognition" has found that the number of rings in the central portion of a fingerprint also varies on the fingers of the left and right hands and so psychologists can simply fingerprint their victims to get some idea as to whether they have more dominant left or right hemispheres.

Studies have also associated relative index and ringer finger lengths with levels of testosterone exposure in utero. Males normally have their ring finger longer then their index one, whereas for females they are usually the same length.

Does the female brain represent and integrate information in a more diffuse fashion?

This remains quite a controversial area with a major source of support being that men are much more likely to suffer from aphasia following left hemisphere strokes than women. However some people have argued that language is just as lateralised in the female brain but in a slightly different location which is not quite as susceptible to strokes. Similarly some studies have suggested that the female brain is less susceptible to cognitive decline following progressive neurodegeneration through ageing or Alzheimer's disease. The largest most recent study in the UK conducted by the Medical Research Council failed to find any significant sex differences. With Alzheimer's disease progression tend to start off in the left hemisphere before the right but again this does not seem to result in either sex having more problems.

Some brain imaging studies have reported evidence for more diffuse activation patterns in female brains compared with male ones but many others have failed to see this. So it is difficult to make firm conclusions from these studies alone on whether female brains really to process information more diffusely.

However, a recent behavioural study using chimeric faces has managed to show a large sex difference in processing positive face emotion with males showing greater lateralisation in the right hemisphere (i.e. they concentrate more on the left visual field) (Bourne, 2004).

Is the female brain better connected?

In general the female brain seems to have proportionately more white matter (fibres) in relation to gray matter than the male brain. This might give general support to the idea of greater connectivity within and possibly between brain hemispheres.

A long standing debate has raged as to whether there are physical differences between the fibre tracts that connect the two brain hemispheres in male and female brains. The main one of these which is the principle connection between the neocortex on the two sides of the brain is the corpus callosum. From large numbers of studies looking for sex differences in this structure it is probably fair to conclude that relative to total brain size it is slightly bigger overall in human females than males (particularly in the area of the splenium that connects visual and association areas in the two cortices in the rear half of the brain). However some other species, such as the rat the opposite seems to be the case with males having a larger corpus callosum than females. But the acid test of whether this confers some kind of advantage in transferring information between the hemispheres has only been investigated in a few studies.

A recent report (Nowicka and Fersten, 2001) used electrical recordings from the left and right sides of the visual and parietal cortices in response to visual stimuli presented either to the left or right visual fields. By doing this they were able to calculate how long it took for information to be transferred across the splenium of the corpus callosum in either direction. Transmission from right to left was identical in males and females (about 5 milliseconds) but from left to right it was much slower (nearly 20 milliseconds which is a long time in brain transmission terms and four times slower than females!). This gives some support for the idea that cognitive interpretations and control of emotional responses by the left hemisphere over the right is slower, and therefore possibly less efficient, in males than in females.

Some final oversimplified conclusions!

- Two brains provides both specialisation and flexibility
- Language and emotional control and interpretation on left
- Social recognition, visuospatial ability and intense emotion response on right
- The two sides can work cooperatively and the left may help control the right
- No real difference in male and female IQ – but different brain strategies
- Males better at throwing things – and hitting the target
- Females know when something is out of place…
- And how to find more of the same
- Females guide you with landmarks, males with directions.
- Females better at verbal and social skills and multitasking
- Males better at focussed attention and mathematical reasoning
- Females communicate their emotions better
- Male brains are more localised
- Female brains are better connected
- Females reliably better appliers and team players
- Males sometimes better innovators and leaders
- … sometimes not much good at anything!

Vive la difference!

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