Sex differences in cognitive abilities have been a widely discussed subject of interest already since the 1870s (for a review see [Shields, 1975](#shields1975)). Inspired by F. J. Gall’s phrenology, research mainly utilised measures of head and brain size in an attempt to explain differences in cognitive capacities (cf. [Cornel, 2014](#cornel2014); [Shields, 1975](#shields1975)). Already early on, it was discovered that men had larger crania and brains compared to women. Researchers such as [Romanes (1887)](#romanes1887) proposed that the comparatively smaller brains of women must be directly responsible for their intellectual inferiority and increased emotionality (see also [Fee, 1979](#fee1979); [Shields, 1975](#shields1975)). In her 1975 review, Shields concluded that many researchers at that time lacked the necessary impartiality to investigate the topic of sex differences, as they aimed “to discover the particular physiological determinants of female inadequacy” (p. 740). Over time as new methods to acquire and analyse (neuro-)psychological data were introduced, several researchers pointed out that those presumed cognitive sex differences were inherently grounded in stereotypical gender roles, and that men and women are more alike than previously assumed ([Broverman et al., 1972](#broverman1972); [Sherman, 1967](#sherman1967); [Woolley, 1914](#woolley1914)).

Even so, the view that the brains and cognitive abilities of men and women are fundamentally different (also referred to as the “gender differences hypothesis”) remained relatively common throughout both the minds of the general population, as well as the scientific community (Hyde, 2005).

With the advent of neuroimaging, new possibilities emerged for more objective research of sex differences in the cognitive neurosciences. Nevertheless, there still is no consensus on the exact neural mechanisms underlying those cognitive sex differences.

Several structural magnetic resonance imaging (MRI) studies and meta-analyses thereof found that the volume of the crania and brain lobes are generally larger in men than in women (Allen et al., 2003; Eliot et al., 2021; Goldstein et al., 2001), with some studies reporting a difference in total brain volume of up to 8-11% (Filipek et al., 1994; Goldstein et al., 2001; Swaab & Hofman, 1984). A study by Allen et al. (2002) found that while the gross volumes of brain lobes differs between the sexes, the proportional sizes of those regions to the total brain volume are nearly identical. Further, it has been reported that certain brain structures differ in (relative) size between the sexes. Some examples include larger volumes in the amygdala, putamen and globus pallidus in males, and larger volumes in the hippocampus and caudate in females (Cosgrove et al., 2007; Giedd et al., 1996a & 1996b). However, such findings are not uncontroversial, as sex differences in the volume of brain structures may disappear when correcting for total brain volume and/or intracranial volume (Choleris et al., 2018; Eliot et al., 2021; Tan et al., 2016).

Numerous studies also report that women have thicker cortices, as well as a higher grey-to-white matter ratio across cortical structures – even after correcting for the difference in total brain volume (Cosgrove et al., 2007; Sacher et al., 2013; Sowell et al., 2006). This effect was found to be especially robust in the inferior parietal and posterior temporal lobes (Sowell et al., 2006; Cosgrove et al., 2007). Generally, men were found to have a higher percentage of white matter (WM) and cerebrospinal fluid (Gur et al., 1999), whereas women were found to have 4-7% more grey matter (GM) than men (Eliot et al., 2021; Leonard et al., 2008; Ritchie et al., 2018). This difference is especially pronounced in the four lobes, the cingulate gyrus and insula (Allen, et al., 2003; Goldstein et al., 2001; Gur et al., 1999). Nevertheless, differences in grey-to-white matter ration have also been reported to disappear after correcting for total brain volume (Eliot et al., 2021; Leonard et al., 2008; Jäncke et al., 2014).

Some researchers consider sexual dimorphism to be stronger in the WM than in the grey matter (Allen et al., 2003; more). Even though men have a higher proportion of cortical WM, women have larger corpora callosa in proportion to their total WM volume (Allen et al., 2003; Gur et al., 1999; Dubb et al., 2003; Ingalhalikar et al., 2013).

Further, multiple studies have found that the corpora callosa of men and women differ in shape: Splenia are larger and more bulbous in women, whereas men have more tubular-shaped splenia, as well as larger genua (Allen et al., 1991; Dubb et al., 2003). Allen et al. (2003) proposed that WM tracts might be less sexually dimorphic than other WM components, such as glial cells and blood vessels.

Studies employing diffusion tensor imaging (DTI) investigated the architecture of WM and its fibre tracts found that over all age ranges, men tend to have increased measures of fractional anisotropy and decreased mean diffusivity than women. Higher measures of fractional anisotropy are thought to reflect increased axonal diameter, fibre bundle density and myelination, while the inverse relation holds for mean diffusivity ([Boespflug et al., 2011](#boespflug2011); [Zasler & Kaplan, 2017](#zaslerkaplan2017)). However, in a similar vein to [Allen et al.’s (2003)](#allen2003) findings of women having larger corpora callosa in proportion to the rest of their WM, [Kanaan et al. (2012)](#kanaan2012) were able to show that the corpus callosum in women has higher FA than in men. This could be interpreted as women’s corpora callosa exhibiting greater efficiency.

DTI may not only be used to study isolated fibre tracts, but also to study the structural connectome of brain networks. Studies have found that women have a greater local brain network efficiency (Yan et al., 2011), as well as increased cortical connectivity (Gong et al., 2009) – independent of total brain volume. A large-scale DTI study investigating sex-differences in the structural connectome by Ingalhalikar et al. (2013) found a higher proportion of intrahemispheric WM tracts in men and a higher ratio of interhemispheric connections, especially via the corpus callosum, in women. Based on these differences in the ratio of inter- and intrahemispheric connections, they argue that men exhibit a greater hemispheric asymmetry than women and further, that these support the hypothesis that differences in hemispheric asymmetry give rise to sex differences in cognitive abilities (Grabowska, 2016; Ingalhalikar et al., 2013; Kovalev et al., 2003; see Hirnstein et al., 2019 for a review).

Generally, hemispheric asymmetry in the functional connectome (also referred to as functional cerebral asymmetry (FCA)) is regarded as a fundamental principle of brain organisation. Well-known examples for this are the left lateralisation of language and the right lateralisation of visuospatial processing (for reviews see Hausmann et al., 2017; Hirnstein et al., 2019), which are present in most, albeit not all, individuals (Kim et al., 1990; Hausmann et al., 1998). A number of studies have compared FCA between the sexes for different modalities and tasks and found small, but robust, effects of women exhibiting lower levels of FCA compared to men tasks (Hiscock et al., 1995, 1999 & 2001; Liu et al., 2009; Voyer, 1996).

There is also some evidence that anatomical hemispheric asymmetries and FCAs are related.

* + Hirnstein et al. (2013) compiled behavioral data from 1,782 participants (885 females) and found that sex differences in the degree of language lateralization, as measured with a well-established verbal dichotic listening task (Hugdahl, 1995), were dependent on age, with the largest effect (Cohen’s d= 0.31) in adolescents. […] The sex difference in this task observed by Hirnstein et al. (2013) is in line with a recent study by Bless et al. (2015) that assessed language lateralization in over 4,000 participants with a smartphone application (iDichotic). This study also revealed greater language lateralization in men than in women, with a small effect of Cohen’s d = 0.18. Although effect sizes in sex differences of language lateralization are small, they are consistent with, for example, recent anatomical findings showing greater leftward asymmetry of the planum temporale (which overlaps with Wernicke’s area) in men than in women (e.g., Guadelupe et al., 2015), which is established very early in ontogenesis (Li et al., 2014).
* Also Hirnstein et al., 2013
* Gotts et al, 2013

[cognitive differences]

* According to this theory, male brains possess greater hemispheric asymmetry with more pronounced intrahemispheric connections, whereas female brains have stronger interhemispheric connectivity and thus, are organised more bilaterally. [where the left hemisphere would be clearly specialized for verbal processing and the right hemisphere for spatial processing. In females, the brain would be more “bilateral”, that is, both the left and the right hemisphere would be carrying out verbal processing]
* [Ingalhalikar et al. (2013)](#ingalhalikar2013) interpreted those findings as male brains being structured in a way that facilitates spatial processing and coordinated motor action, while female brains promoting attention, memory and verbal abilities.

[sex hormones may be the reason for differences in hemispheric asymmetry]

Many researchers argue that those differences in brain organisation and cognition may be caused, or at least influenced, by sex hormones (e.g., Cosgrove et al., 2007; Grabowska, 2016; Kimura & Hampson, 1994; Varnava et al., 2007; Hirnstein et al., 2017)