The differences in brain structures and blood flow between male and female

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Abstract

This paper will analyze the sex differences found in brain anatomy. In particular, the grey and white matter, the cerebral blood flow, and more specific regions will be investigated. The global volume and particular areas of grey matter, white issue, and blood flow will be included. Their differences will also have some emotional factors discussions. Information and data collected from papers before are used to conclude the end. Men undoubtedly have a more considerable brain volume, and females have higher total cerebral blood flow. The sizes and neuron numbers in the specific constituents still doubt it. The possible purpose of such research is to develop in the sociology and medical sectors.

Keywords-sex differences, brain anatomy, gender dimorphism, cerebrum, grey and white matters

1. Introduction

Brain science studies between sex differences and the brain can be dated early to 1969 [1]. According to some papers [3, 21, 40], this physiological contrast is mainly due to different sex hormones exposures, environmental factors, and some gender-specific diseases that could be related to it [13].

Turning to the brain structure, the cerebrum is the most significant part of the brain. It can be divided into four lobes made of grey matter [2], including the temporal, frontal, parietal, and occipital lobes. Each contains certain gyrus and cortexes, and they perform specific functions. Around the brain, the cerebral cortex covers the cerebrum, and it contains nervous cells. The cerebrum also has many specialised structures in the lower part, such as the thalamus, the hippocampus and the amygdala.

This paper will review research on differences in brains anatomy, and a conclusion on this will be provided. Data collected from various papers includes previous brain scanning and early reviews. These will be compared and discussed, and finally, a conclusion will be drawn based on the analysis.

This paper will discuss the structures and sizes of each constituent. The grey and white matters will be first evaluated, followed by amounts of blood flow and cerebral differences. In addition, we will also review the global brain difference and the mentioned structures. The results at the end will also be compared to previous similar literature reviews [16, 19, 22]. This study can give possible reasons for contrast in characteristics and applied in psychology, sociology, or neuropsychiatry [24].

2. Grey and White Matters

Grey matter (GM) is a somatodendritic tissue made by nervous cells without a myelin sheath. In contrast, the white matter (WM) contains it to transfer information to distant regions [18]. It is called white, as the myelin sheath is a white fat tissue. Those matters could be responsible for cognitive abilities, and abnormalities in those matters could cause dyslexia [5]. One's sexual orientation and gender identity may also be attributed to the GM and WM [11]. In addition, both cortical and subcortical grey volumes may contribute to factors affecting IQ [6]. In this sector, dissimilarities in GM and WM volume in specific gyrus and cortex will also be included.

The overall volume of GM and WM in the whole brain was associated with the total brain volume. More extensive brain volume is more likely to have more excellent GM and WM volume, and this case was found to be more significant in men [18]. Furthermore, in Allen et al.'s paper, WM differences are more noticeable when viewing sexual dimorphisms [21]. Under most circumstances, man has higher GM and WM volume [18,21-23] except in the left and right occipital lobe, the right parietal lobe and the right cingulate, a structure above the corpus callosum [21]. However, some contradictions were given by previous studies. Gur et al. found that women have higher GM volume than their male counterparts. The authors concluded it was probably due to different experimental techniques [18]. In addition, another contradiction is given in pointing out that women have a larger total WM volume [27]. Another study proposed that women could have greater GM volume when whole brain size is considered, as women have smaller brain sizes [24].

The total distribution of GM and WM is similar in both women and men [27]. Generally speaking, women have a higher WM to GM ratio than men [5, 21]. Allen et al. provided extra information indicating exceptions in the

left temporal lobe, left cingulate and insula [21]. MTR research in studying the fornix white matter volume relating to adolescents [4] and DTI experiments examining total brain volume [14, 15] illustrated a few graphs and tables suggesting that women have greater WM volume. Nevertheless, these papers and other FA and xenon experiments [14, 15, 18] to measure WM concluded that men have a larger total white matter volume than women. Again, the experimental methods and models may account for the authors' choice [14, 15]. However, an alternative was shown in one study that also uses the FA measure for WM. They concluded a result, saying that females have higher WM in corpus callosum than males [13, 21].

2.1 Specific areas of white matter

In terms of specific regions, two studies showed that males have more WM volume in the anterior parts [9,10], with one mentioning to have higher in the temporal stems bilaterally [9], and the other suggesting higher in the left SLF (superior longitudinal fasciculus) [10]. A VBM (voxel-based morphology) showed a higher concentration for males' WM in the temporal and posterior front lobes. Also, the suitable material and in the right percental gyrus (in the posterior frontal lobes) for male adolescents [22]. Their female counterparts have more WM volume in the posterior front lobes and the left stem [9]. Gender differences in WM and GM in the parietal lobe are insignificant, but women have a more excellent GM: WM ratio [60].

2.2 Specific areas of grey matter

According to Chen and Luders' paper, males have a higher total grey matter volume while females were preserved to have higher regional GM volume in certain regions [23, 27]. For example, the posterior temporal lobes [9, 27], in right orbital gyri and inferior frontal gyri [9] (located in the frontal lobe), the left angular gyrus, and the left superior parietal gyrus (located in the left parietal lobe) [22, 31] and the overall volume in the right occipital and parietal lobe [21, 27, 31]. As for the male, they were observed to have higher and very symmetric GM volume in the amygdala and hippocampus, in the left anterior temporal lobe (to be specific, the entorhinal and perirhinal cortex) [9] and in brain steam [22]. This is explained by sex hormones, where progesterone is more associated in the right temporal lobe and testosterone is related to the left inferior frontal gyrus [22]. Another MRI research supports this with extra details: testosterone was linked to the hippocampus [25]. An interesting result indicates that females have higher GM in the adjacent Broca's area, used for language processing [27]. This corresponds with the high GM in female inferior frontal gyri as Broca's place is. Female brain development was also more sensitive to sex hormones [25].

Some studies provide not only sex-brain connections but also sex-age-brain correlations. As age increases, white matter volume also increases [24,4]. Perrin et al. showed that women had increased white matter volume over time, whereas men are the opposite [4]. The explanation is that women have denser and smaller axons, but males have more widespread axons [4]. But both sexes appeared to have an increase in WM in Lenroot et al.'s studies. An MRI study concludes that males initially have higher WM and GM volume. This corresponds with Lenroot et al., in which men have a higher increase rate of GM and continue to have higher WM volume during development. Females showed much higher GM volume than total brain size and a minor WM to GM ratio [10]. However, this smaller ratio differs from the higher WM: GM ratio for women.

Since there are contrasting data in the absolute amounts of WM and GM, it cannot be summarised into one exact answer. But in some subunits, the frontal and temporal lobe have higher differences in WM and GM, but the parietal is only shown in GM.

3. Blood flow in the brain

Unlike grey and white matters, there are fewer studies on blood flows, especially the regional blood flows related to sex dimorphisms [36]. Older people tend to have fewer sexual differences [36, 48] in their brains so that the main focus will be on adults and adolescents. Usually, the cerebrum blood flow decreases with ageing, and men have a less significant decline [40, 48, 50]. This correlates to some findings saying that oestrogen may be the leading cause. Blood flows abnormalities seen in diseases like schizophrenia may be due to gender differences [40].

Most normal people have a higher flow in the front of the brain [40]. Female has much higher total cerebral blood flow (CBF) than male [36, 38, 40, 43, 48, 51, 55], and regional cerebral blood flow (rCBF) does not reveal to have much sexual differentiation [36]. Some regions of interest showed higher CBF in women. This includes the anterior cingulate cortex [41, 43], left hippocampus/putamen, and left and right occipital lobes [43]. The most significant area is the inferior frontal gyri [43]. Three main reasons for high CBF in women are the higher superior temporal gyrus grey matters and metabolic rates in women Schlaepfer et al. [38]; women's menstruation which may increase blood viscosity in specific regions and periods Shaw et al. [37]; other endocrine factors and sex hormones by Gur et al. and Liu et al. [40, 48]. Furthermore, females have more flow in a grey matter [40, 48] and white matter [48]. Few papers also concluded that CBF values do not show differences [49, 50]. However, an opposite finding showed adolescent women have lower flow in the anterior and higher in the

posterior like the right inferior frontal areas [36]. The males have more flow in the insula cortex and the DLPFC, which means men will be more cognitive when repressor of this region flow happens [41]. Although women have greater blood flow, men have more haemoglobin [49]. Moreover, women have higher asymmetries of flow in anterior temporal areas. On the other hand, men have more frontal asymmetry [36].

Females' rCBF were more responsive to emotional state changes when it comes to dynamic changes. Women can activate the right caudate and left anterior cingulate during happiness, and men also activate the right caudate and left putamen. Women have increments in blood flow during sadness in limbic and paralimbic structures [39]. When resting, they have decreased blood flow in the right anterior temporal, and right prefrontal region, and men experience an increase in rCBF of the brainstem [39]. In a positron emission tomography study, three cognitive tasks were conducted. Females showed higher CBF in two functions, suggesting that men and women may use different pathways to achieve identical scores [43].

Based on the studies mentioned above, females have higher CBF than males, but men exceed women in small subunits, and females also exceed women in other sectors. In different emotional statuses, both men and women activate different brain parts.

4. Structural differences in cerebrum and corpus callosum

The cerebrum is the most significant part of the brain, and the cerebrum is made up of two pallia connected by the corpus callosum. The right hemisphere is slightly bigger than the left for most subjects [31]. Its function is also for controlling cognitive abilities like the WM and GM. Below the cerebrum is the cerebellum, which is only 1/9 of the cerebrum in size [13]. It controls the movement of the body [12]. Covering the cerebrum is a backbone called the cerebral cortex, and several studies reported sexual orientations and gender identity [8, 33, 34] relating to it. For instance, transgender males and females have smaller cortical thickness than cisgender people [8]. Although there are varied papers and data in studying relationships between sex and brain, an apparent consistent pattern on the points of men having larger brain volume [7,9, 16, 18, 22-24, 28, 29, 44] with approximately 10% [24] or 14.7% more significant [28]. Moreover, females' asymmetric metabolic rates are much smaller than males [46]. Cerebrospinal fluid is debated as most paper agrees that male has more CSF [18, 22, 9, 23], and some minorities revealed that there is not much difference in CSF actually [27, 31].

4.1 Lobes and hemisphere

When age is considered, young males have higher frontal areas than elderly males. Females have continuous value in volume when concerning age [45]. This happens to their temporal lobe, too. This is partly consistent with previous studies indicating that men's decline in right FT (Frontal lobe) is more sensitive to age and right temporal lobes [46]. They will also have rightward asymmetries as RFT lobes will be bigger than the left. The rightward asymmetry also occurs in the frontal lobe [45]. Women's insinuation of the brain is much less associated with age than men's [29]. In the parietal lobe (PT), females have more decline with ageing [46]. However, not many sex differences are found in the parietal lobes. Only men have a more extensive surface area in the PT lobe than women [60]. But the situation may change when looking at the hemisphere like women have a bigger left parietal: left hemisphere ratio and smaller left temporal: left hemisphere ratio than males [29]. A study using music and noise showed women more activity processing in the primary auditory cortex [47].

4.2 Thalamus

The thalamus transfers information from the peripheral and subcortical areas to the cerebral cortex [26]. Several types of sexual and non-sexual dimorphic neurones are present in the thalamus, for example, the sexually dimorphic nucleus (SDN) and paraventricular nucleus (PVN) [52]. Gender identity, reproductive behaviour and sexual orientation are due to structure and neurones present in the hypothalamus [34]. If thalamus structure changes, emotional and painful feelings could be the reason [26]. The metabolic rate in the thalamus is higher than in women at the age of 24 [46].

Women were found to have more overall nuclei in the thalamus and caudate [46]. In the hypothalamus, the SDN-POA cell number increases the same for both girls and boys, and no gender differences are shown, but then females decline later [34, 52]. Similar situations occur in the SDN [35]. The correlation between a decline in neurones but higher findings of the nucleus in women is not consolidated.

The nuclei found in the intralaminar and midline function to control one's consciousness and awareness. It declines in age, but women respond to it less [30]. This is the opposite of the SDN situation. In terms of vasopressin neurones, males have more giant neurones in SON and PVN, but there are no significant differences in the volumes between genders [32]. However, Van Londen et al. reported some sexual dimorphism [33]. This increased activity and oestrogen secretions explain this, and neurones contrasts stop at age 50, supporting the oestrogen claim [32].

4.3 Corpus Callosum

CC is the most significant inner connective tissue between the two hemispheres [61]. And hemispheric lateralisation is

related to the corpus callosum [26]. Women have slightly higher corpus callosum volume compared to men [24]. But one study shows that the absolute importance of CC has no sex effects on it [63]. Another study showed that men have higher CC volume than women [61]. No correlation between gender and the brain's asymmetric structure and corpus callosum was observed [9,18]. This is unlike the hypothalamus, where gender does affect asymmetry. Shapes also differed, with females having bulbous-shaped splenium and males having tubular-shaped splenium [61]. With age-sex related findings, women will have more expansion in splenium than men, and men have more decline in size in the genu than women [62].

4.4 Cerebral Cortex

A wide range of cortical diseases may be related to the sexual dimorphism of cortical differences, including mental retardation and speech abnormalities that happen to men more [56]. There were no significant differences in cortical thickness, gyri or sulci between males and females [31, 56]. However, Luders et al. presented that women have thicker cortical thickness, with the left FT lobe and paracentral lobe being most different. The constituents align with other areas in the left posterior FT lobe where man is thicker [54]. Another MRI study provided similar results, but the broader area of males is in the frontal, parietal and occipital lobes. Furthermore, the left hemisphere showed more significant results [64]. Men also have denser neurones in the cortex, especially in the visual cortex [56].

4.5 Hippocampus

The hippocampus (HC) can be divided into the anterior, posterior and middle. This relevance to spatial activities performed by the two genders is found [65]. For younger women, hippocampus volume is more significant than males, but gradually becomes the same when the two groups are old. This is due to women having decreased hippocampus volume as age increases. [46]. Some MRI studies explored men with larger hippocampus volume [57, 58] and males with higher GM in the anterior HC [65]. However, also another study showed women to have more excellent posterior HC, and the anterior HC was nearly the same for everyone [58]. Females have more posterior HC but not many differences in the absolute right or left side [65]. The neurones of men in this sector are more complicated than women's [66]. Furthermore, women have higher metabolic rates than men until reaching their 70s [46]. The different neurones in the hypothalamus and cerebral cortex will not undergo the same paths when looking at gender factors. Corpus callosum volumes have varied data and may need more references. Although cortical thickness differs in different areas, we may suggest that men have slightly thicker CT.

5. Conclusion

Overall, this paper reviews gender differences in significant sex dimorphic brain structures. According to documents referenced above, we can draw the following conclusions. Men have a greater brain size than women. Moreover, men have total GM and WM, whereas women have higher absolute CBF. However, in both situations, there are exceptions in different subunits. The sizes of the lobes, corpus callosum and hippocampus, have different conclusions from various papers, so the differences in these fields are still mooted. Even though there are many reasons for the difference in blood flow, the exact answer is still unclear. The sex-dimorphic neurones in particular sectors like the hippocampus and cerebral cortex are not enough studied yet. More future in-depth studies are required to solve this puzzle.

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