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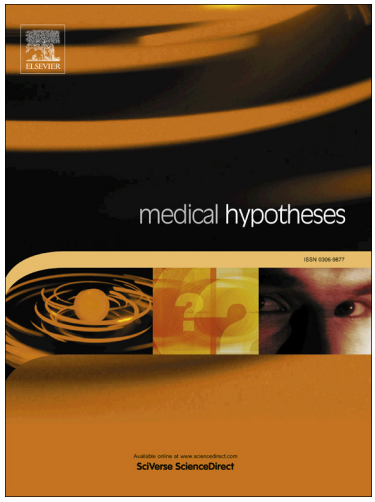

The glass ceiling: a biological phenomenon

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Introduction

Many doctors, scientists and managers have the experience that brilliant and ambitious young women, qualified and capable for top careers, lose their interest in such a career after childbirth and make choices in favour of parental roles instead. This phenomenon of apparent loss of ambition is ascribed to socio-cultural factors. Now, after the appearance of hundreds of articles about brain plasticity in pregnancy and lactation in animals and an increasing number of publications about brain changes in humans, it can be stated that this decrease in ambition is primarily caused by changes in the brains of young mothers. Many high-potential mothers feel under pressure to strive for top positions, either socially or pushed by organizations, institutions and governments, some aiming at minimum quotas of women participation. I submit the hypothesis that the choice not to go for the top is based on a biological substrate and is mediated by changes in hormonal concentrations and brain structure.

Brain Plasticity

The brain is not static, but is constantly changing. It has the ability to reorganise itself, throughout life, both physically and functionally, under the influence of environment, behaviour and emotions. When people learn new motor skills, such as playing a musical instrument or a sports activity, there are plastic changes in the structure and organisation of cells in the nervous system that facilitate these skills. Extensive research in animals, especially rodents, has shown that adult neurogenesis creates new cells which migrate and differentiate into new neurons and glia cells (1). Synaptic connections are made or removed all the time. Several areas are involved, specifically the subventricular zone, the dentate gyrus of the hippocampus with its cognitive and memory capacities, and the olfactory bulb for the faculty of smell, which is so important in animals (2).

Hormones, especially pregnancy hormones have been demonstrated to be of primary importance for adult neurogenesis(3).

The influence of pregnancy and lactation on the animal brain

Brain changes in pregnancy have been demonstrated already for decades. Oxytocin, oestradiol, progesterone and prolactin stimulate changes in hippocampus, amygdala and hypothalamus, particularly its medial preoptic area. In rodents this so-called maternal circuitry is crucial for the onset, maintenance and regulation of maternal behaviour like nest building, grooming and nursing, but also for control of fear and anxiety, memory, (spatial) learning and increased speed of prey capture (3,4). These changes persist throughout the lifespan of the rodent. Improved spatial orientation was still persistent at the age of 24 months (roughly equivalent to 70 years in humans), compared to virgin rodents. The more pregnancies, the stronger this ability (5). Experiments with food searching showed a permanent improved ability with persistent brain alterations at later age (6). Pregnancy induced neurogenesis has been demonstrated in sheep as well (7). Thus, there is considerable evidence that the reproductive experience modifies the female's brain (8).

The influence of pregnancy and lactation on the human brain

Changes in behaviour, memory and skills during and after pregnancy and lactation are well documented in neuropsychological research (9,10). Functional neuro-imaging studies also show the existence of a human maternal circuitry within the limbic system including hypothalamus, hippocampus, amygdala and the substantia nigra (11). The human mother however needs special cognitive and social skills to raise her child in a complex society. Additional high-order abilities are needed, such as empathy (the ability to share the feelings of the infant) and theory of mind (the ability to understand infant's thoughts, desires, intentions and feelings).

Connections between limbic and cortical systems like the theory-of-mind network and the mirror neuron system have been demonstrated. Increased brain activity in these regions has been observed when mothers reported a positive feeling about photos depicting their own babies, compared to unfamiliar babies. The same was found for the crying of their own babies (12).

Recent research by Hoekzema et al showed that pregnancy is associated with pronounced and long-lasting brain changes, primarily located in regions involved in social processes such as feelings of empathy and the ability to understand others. The changes in these regions, which are notably similar to the theory-of-mind neural network, significantly predicted the quality of mother-to-infant attachment. After two years, the brain changes were still present, indicating that they are long-lasting or perhaps permanent. Just by looking at the brain scans one could tell which women had been pregnant and which had not (13).

An unexpected finding was a reduction in brain size rather than an increase. This reduction is explained by the process of synaptic pruning, leading to a newly and better organized brain. The same process is known in adolescence when brain reduction is a result of fine tuning connections into functional networks, necessary for a healthy cognitive, emotional and social development (13).

It can be concluded that, as in animals, the human maternal brain undergoes fundamental and long-lasting changes during pregnancy and lactation.

The father's brain

This is not only a story on women; the administration of several hormones has an effect on males' behaviour as well. For example rams will behave motherly after oestradiol administration and human fathers show more interest in their children after inhaling oxytocin nasal spray (14). This also resulted in activation in brain regions involved in empathy and in attachment to offspring (15). When father mice are frequently exposed to their offspring, their behaviour in care and protection changes. The brain structures, mainly corresponding with the maternal circuitry, show small but clear anatomical changes, accompanied by changes in hormone levels (16).
Similar observations have been found in humans. Functional MRI studies reported brain activation in response to infant visual stimuli that overlap in mothers and fathers. The more fathers are involved in raising their children, the more caring behaviour they develop (17).
Kim et al found structural anatomical changes in neural regions involved in paternal motivation four months after the birth of offspring. The same regions were activated when fathers watched video clips of their own child. This did not happen with similar images of unfamiliar babies (18). These exploratory studies show that brain plasticity in fathers is experience-dependent.

The glass ceiling

The notion of a maternal brain explains why so many brilliant and ambitious women, capable for a top career, lose interest in pursuing such careers after childbirth. Their new maternal impulses are at odds with their original ambitions, and for many mothers stress and frustration will be the result. If they continue to strive for the top, they will feel guilty towards their children. If they give priority to their children, they might receive scorn from other women and society. Even those who have a well organised home setting with adequate help from family, nanny or houseman, will find it hard to have work weeks of 60 to 80 hours, which is not an uncommon price to pay in the competition for top positions. Men appear to care less to spend, or waste, so many hours, often thanks to their (part time working) wives.
Perhaps the introduction of a long paternity leave followed by part-time work would result in fathers finding more satisfaction in child care, and less in the often frustrating pursuit of top positions. For many, work weeks of 60-80 hours, will become too high a price to pay, which would level the competitive playing field for mothers. Then a more equal participation might be within reach, not as a result of policy fighting biology but as a natural outcome. This would also be more in line with the evolution of mankind as cooperative breeders with shared caretaking or even alloparenting (19).
Extensive paternity leave is existing in most Nordic countries with an individual, non-transferable right to 2- 3 months paid paternal leave followed by a flexible shared parental leave of several months with state-mandated financial benefits (20). Demolition of women's glass ceiling starts with men, not as policy makers but as fathers.

Conclusion and future research

Policy-driven targets for women in top positions will be hard to reach. Research findings show long-lasting structural brain changes in mothers after pregnancy and lactation, altering their behaviour and priorities. It should be accepted that there is such a thing as a maternal brain and that biology urges mothers to be with their children. As brain changes are also demonstrated in

child caring fathers, a policy change is needed with respect to paternal leave and subsequent parental benefits.
To test the hypothesis, prospective and longitudinal studies with sufficient power could be performed in young couples with a desire to get children of which the female has reached a good position in research or business and has the intention to continue her career after the baby is born. The cohort could be divided in couples where the father gets a fully paid paternal leave of at least a few weeks compared to couples with no or a few days paternal leave. In order to assess the effect of lactation, the cohort could be divided into females who plan to lactate and those who do not. Brain function and (non invasive) hormonal tests of both men and women can be performed before pregnancy, in late pregnancy, at some time points during parental leave and after restarting work, preferably in several countries with different duration of parental leave. The Nordic countries can serve as an example. The influence of more or less paternal care on the career of both father and mother could be assessed as well. With regard to brain testing, there is a need for more naturalistic stimuli to relate brain function in the scanner to behavior in every-day life. Precision of the regions of interest with exploration of the cortico-limbic circuits and a connectivity analysis is needed. Important is a proper adjustment for potential confounders (e.g. stress and sleep deprivation).

Summary

Many brilliant and ambitious young women lose their drive for top careers after childbirth. New maternal impulses are at odds with their original ambitions and for many mothers stress and frustration will be the result as they have to combine child care with workweeks of 60 to 80 hours to reach or remain at the top. Pregnancy hormones modify the female's brain as has been demonstrated already for decades in animals. This brain plasticity due to adult neurogenesis in the so called maternal circuitry of the limbic system is long-lasting and perhaps lifelong.
In humans hormonal and neuro-imaging studies show ample evidence for fundamental and long lasting pregnancy induced brain changes, not only in the limbic system, but also in the cortical networks like theory of mind and mirror neuron system. Recent research shows pronounced and long lasting brain changes in several of these areas. It can be concluded that there exists a maternal brain that drives mother's behaviour and priorities. Research in men shows that the more fathers are involved in raising their children, the more caring behaviour they develop. Structural anatomical changes are found in neural regions involved in parental motivation. These studies show that brain plasticity in fathers is experience dependent. In Nordic countries, a policy of paid paternal leave followed by a flexible shared parental leave, stimulates fatherly behaviour. This might reduce men's eagerness for top careers, thus creating better opportunities for women. Demolition of women's glass ceiling starts with the father.

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