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THE LIMITS OF THE BRAIN

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Friends and Distinguished Guests

Ladies and Gentlemen

I am delighted to be here today to join you at your annual banquet.

I am greatly honored to be invited and asked to give an oration. You are an august body with enlightened members with interest in many medical and non-medical areas that there are only a few topics that I can speak on. I have spent much of my adult life focused on the brain and so I would like to share some of my thoughts on this fascinating organ.

I first touched a live human brain 23 years ago. I was a house officer in a surgical unit who diagnosed the presence of a blood clot in the brain through my clinical examination of a patient who had a head injury. I assisted the surgeons during the surgery. The brain was bruised and oozing blood. The surgeons cut a piece of muscle from the temporalis muscle and asked me to grind the piece of muscle in a mortar. They then placed the meshed tissue on the surface of the brain and I was asked to hold it in place for 15 minutes by gently compressing the meshed tissue on the surface of the oozing brain. I could feel the pulsations of the brain. I was awed by what I was doing. I did not expect the patient to live. But the oozing stopped, the patient recovered and left the hospital; and I decided to become a neurosurgeon. Over the last 23 years, I have worked on and in the brain but I have never lost the sense of wonder and awe that I feel when I look at the brain.

Hippocrates, the father of medicine knew the central role of the brain. He said: “Man ought to know that from the brain, and from the brain only arises our pleasures, joys, laughter and jests, as well as our sorrows, pains, grief and fears. Through it in particular, we think, see, hear and distinguish the ugly from the beautiful, the bad from the good, the pleasant from the unpleasant.”

The brain is a 1.3 kg mass organ that has the feel and look of bean curd. It is made up of 100 billion nerve cells or neurons. You may think this is complex but this is just the beginning of the brain’s complexity. For each nerve cell there are about 10 glial cells. That means there are a thousand billion glial cells. They form the scaffolding of the brain; they provide insulation for the electrical activity of the nerve cells. They clean up after chemicals are released by nerve endings. We know little about glial cells, but assume they do all the house-cleaning functions in the brain. Each neuron may receive thousands of inputs and in turn connect to thousands of other neurons. Each connection is called a synapse and so there are trillions of synapses that make the brain a circuit. A standard computer has a single CPU- for example a Pentium IV from Intel. A duel processor will have two CPU processing in parallel. The brain has millions of CPUs each as complex as a Pentium IV and all processing in parallel. This parallel processing is the basis of the enormous capability of the brain.

Ten years ago, scientists had only unraveled fragments of the human genome. It was assumed that many of the unknown genes must code for the brain. The genome of the fruit fly was sequenced in the year 2000. The size of the genome is 180 million base pairs and contains 13,061 genes. The human genome is 30 times larger than the fruit fly and contains about 3 billion base pairs. It was assumed that our genome must therefore contain about 300,000 genes. The lower end of the estimate was about 100,000 genes. It was also assumed that most of the unidentified genes coded for the brain. After all we are so very smart and can do so many clever things. The decoding of the human genome this year has been humbling. There are only about 26,000 genes in the human genome. Most of the millions of base pairs in our human genome do not code for any genes. We consist of only twice as many genes as the fruit fly. The chimpanzee and even the little mouse has about the same number of genes as we do.

How then do we explain our superior brain? The answer is that we do not need many genes to create a superior brain. Among the Amish are born children with extremely small brains, a congenital condition called severe microcephaly. Geneticists studied the Amish and found that a single gene controls the increase in size of the brain. We are separated from these children by a single gene. We all have this gene and that makes our brain cells divide many more times than these children and therefore we have a brain many times larger.

Most people intuitively think that our brain develops like a plant. You have a seed and it grows and grows and develops into a plant. In the same way we like to imagine that our brain cells divide until they reach the complexity of the adult brain. This is only partially true. Our brain cells develop from a structure called the neural tube which proliferates rapidly, dividing and dividing multiple times, giving us billions of brain cells within the first 3 months of fetal life. They then stop dividing and never divide again. This is one of the basic limits of the human brain. After this fetal period, brain cells do not divide.

There is then a Darwinian battle among the brain cells to make connections. Nerves that connect up live and those that don't die. We lose between 90 to 99% of our brain cells when we are a fetus; and remaining survivors who have made the correct connections persist into adult life to produce a 1,300 gm functioning brain. It might seem such a waste to lose so many brain cells as a fetus, but this fact should not overly surprise obstetricians and gynecologists who know how wasteful biological systems can be. A woman releases about 450 eggs during her reproductive life. A man produces enough sperms to populate the whole world several times. Yet average couples with two children use only two eggs and two sperms, the rest of their reproductive potential is wasted. Compared to the biological waste in reproduction, brain development is remarkably less wasteful.

We are losing brain cells everyday and these lost brain cells are not replaced. When we lose about half of the brain cells that survived fetal life and the brain weighs about 700 gms, we exhibit signs of senile dementia. It would appear logical that if we started out with a larger number of survivor brain cells when we are born, we would delay dementia. We want our children to be as intelligent as possible. We also want them to avoid senile dementia when they grow old. The health of the fetus is therefore important. Obs & Gyn specialists therefore have a great responsibility in ensuring the in-utero health of the fetus. I am confident that as science progresses, there will be more that we can do to protect the proper development of the fetal brain.

The power of the brain is dependent on more than just the number of brain cells. Its power lies in the formation of connections that form the neural circuit. We have just begun to understand some of the mechanisms involved mainly through the study of the visual system. The nerve cells in the eye travel to the back of the brain and make connections in the occipital lobe. There are only a finite number of connections. Any nerve cell that does not make a connection dies. There are many more nerve cells than connections so the majority of nerve cells from each eye will die. Normally half the survivors, that is, nerve cells that make a connection come from each eye. In experiments in monkeys, if one eye is removed, then all the connections will be made to nerves from the remaining eye. Since this eye will have twice the number of connections as it does not have to compete with nerves from the other eye, the monkey visual acuity in this good eye is better than that of a normal monkey's eye. However, since it has only one working eye, the monkey does not have stereoscopic vision, that is the ability to estimate distance. This experiment shows an important principle – the brain has limits in its ability. If we improve visual acuity by sacrificing one eye then we will lose stereoscopic vision. Or to put it in another way, the price of stereoscopic vision is the reduction of visual acuity in both eyes. This principle of limited capacity of the brain may apply to other functions of the brain, including language.

The function of the brain and our ability to use language are intimately connected. Language is the remarkable system that allows people to communicate with each other in an unlimited combination of ideas by using a highly structured system of sounds. We developed this ability about 50,000 to 100,000 years ago. This function of the brain is unique to our species and allows us to imagine and speculate about our own origin and our death, the smallest atom and the largest universe, and about God and abstract logic.

5000 years ago, man developed the innovation of being able to record his spoken language in a permanent manner so that knowledge and information could be preserved and shared. This was an applied innovation without any evolutionary change in the nature of the brain. All civilisation is based on this ability. This led to an explosion of knowledge with new understanding of things built upon the work of previous generations. About 100 years ago, Darwin and Mendel laid the foundation of evolution. About 50 years ago we had the Watson and Crick double helix model of DNA. Today, we have unraveled the human genome and school children know they can have a record of their individual distinctive genome on a CD. School children perform gene transfer experiments in their classrooms.

All of this is possible because we can record and transfer knowledge across generations. But our brain has not changed in the last 5000 years. We still have to cope with language in the same way as we did 5000 years ago. Languages are learned. Children who grow up in the wild, the so-called wild children occasionally encountered in the past and those who grow up in a silent world are invariably mute.

Charles Darwin noted “Man has an instinctive tendency to speak as we see in the babble of our children”. In the first year of life, children work on sounds. They begin to make language-like sounds at about 6 months. Initially all children make a wide range of sounds that gives them the capacity to learn all the known human languages. However this range rapidly becomes restricted as the child learns to discriminate specific sounds and limits his ability to produce sound to the sounds that he hears in the language spoken to him. So a child growing up in a Chinese speaking environment will usually not be able to pronounce “r” since this sound is not used in Chinese; and ‘Robert’ is usually pronounced ‘Lobert’, Likewise, a child in an Tamil environment will call a vase of flowers, a ‘wase’ of flowers because the Tamil language does not distinguish ‘v’ from ‘w’.

There was no evolutionary reason for the brain to learn two languages 50,000 years ago; but today, it is the prime worry of parents. We could help children by exposing them to two languages from an early age so that they retain the ability to make the sounds needed for both languages. But there could be a problem. The child instinctively picks up vocabulary and grammar in the first few years of life. From our experiments with the visual system, we know capacity is limited. Will exposing the child to two languages at an early age result in a bilingual child but one whose vocabulary is reduced in both languages? Will there be a fusion of the vocabulary when they express themselves. I hear this whenever I overhear young people converse among themselves. – “Wo men qu kan movie”. “Ta shi hen cute”. Will there be problems with grammar. We hear young people say, “I have eaten already”. The word “already” is not necessary in this sentence if we want to use the English language correctly; but Singaporeans add the word because they are following the language construction of the Chinese translation – “Wo chi wan le”. Singlish is the fusion of the components of bilingualism.

Educationalists and policy makers must learn to sympathize with parents and our young student’s difficulty in managing bilingualism because our brains were not developed for such an environment. Policy on language must therefore take into consideration this limitation of the brain.

It is said that although we men like to act macho, under our macho exterior there is a sensitive feminine side to us. I am not sure if this is true but we do know as a scientific fact that the basic sex of our brain is female. When the fetal brain is exposed to testosterone, the brain becomes masculine and the masculine behavior is imprinted permanently. There are permanent anatomical changes in the brain as a result of this masculinisation. The behavior of boys and girls is different and in some aspects pre-determined before birth. Boys will choose guns and Power-Ranger toys. Give them a Barbie doll and they will dismember the leg and use it like a toy gun. That males and females think differently is obvious. You just need to look at men’s magazines and women’s magazines to see the difference.

Scientists who in the past were predominantly male found that the male brain was on average slightly heavier than the female brain. This is really not surprising because the male is on average heavier than the female. This increase in weight is not due to the heaviness of the male reproductive organs. The increase in the average weight of a male compared to a female, is due to the increase in the average weights of most organs in the male as compared to the female. Many male scientists have assumed that the slight increase in weight of the male brain means that the male is generally superior in the area of intellectual ability although there is no scientific proof that this is so. Today we can calculate the weight of any person’s brain by doing a CATscan or MRI. But we do not use this mechanism to judge ability. We do not select scholars by the weight of their brains but by their ability. So should we discriminate against women? Sometimes, women’s biological role to bear children is the cause of institutional bias against females. However, this has the negative effect of more and more women shunning their biological role to bear children. This leads to a declining population growth rate. This is a matter of concern to us in Singapore. It is clear that we need to review policies such as the quota on female medical students.

On the other hand, should we blindly aim for statistical parity between males and females. Women often quote statistics that show men occupy a higher proportion of top positions as evidence of discrimination. All the neurosurgeons in Singapore are male. This may be the result of the clearly proven tendency of the male brain to take risks. So although males form a disproportionate number of CEOs and neurosurgeons, they also make up most of the young who die in accidents and of course males form a clear majority of the murderers and perpetuators of violent crime. The male brain is intrinsically more prone to violent behavior than the female brain. Although this may be a socially negative factor, the ability to fight is needed in combat soldiers. That is why combat national service is restricted to males. We can only achieve equality in self-expression and development for males and females in society if we first recognize that the male and the female brain are different and cannot be changed. We must therefore work within these limitations to achieve parity and fairness between the sexes.

Research has also shown that the brain of homosexuals is structurally different from heterosexuals. It is likely therefore that the homosexual tendency is imprinted in the brain in utero and homosexuals must live with the tendencies that they inherit as a result of the structural changes in their brain. Within the moral and cultural constraints of our society, we should be tolerant of those who may be different from most of us.

As a neurosurgeon, I was always amazed by the many patients who showed changes in their behavior often of a subtle nature after a head injury that affected the frontal lobes of the brain or after a rupture of an aneurysm at the base of the frontal lobes. Our genes imprint patterns of behavior into our frontal lobes and we then behave as our frontal lobes tell us. Although human behavior is culturally diverse, basic patterns of behavior remain universal and identical across all cultures. Eating is a normal human activity. So is sex. Yet we frequently get together in public, like we are doing tonight, to eat together as members of a community, as a social act of community bonding. But we do not get together to have sex in public. All over the world, whatever God people worship, and however many clothes or few clothes they wear in public, sex is a secret act done in privacy. This is a universal human characteristic. Eating food on the other hand is just as universally a communal activity. These patterns of behavior are written into our genes and expressed through our brains in the frontal lobes without us really considering the origins of our behavior.

In the same way, the propensity for violence in human behavior is universal. Rousseau thought that there was nothing more gentle than man in his primitive state. But is our primitive state really gentle? Jane Goodall spent most of her life living among and observing the behavior of chimpanzees. She described the many human-like behavior traits of chimpanzees and she initially reported their gentle nature. However after a longer period of observation, she found chimpanzee society similar to human society. Chimpanzees wage war and massacre their enemies much like humans. Our brains carry within them the inherent pattern for violent action. We cannot change this and it is one of our limitations as a species. But it can be held in check and it is held in check if there is deterrence. There is no such thing as the gentle noble savage and closer examination of tribal societies that still existed in the 20th century shows high rates of violence and violent death.

Winston Churchill summarized our species in the following manner, "The story of the human race is war. Except for brief and precarious interludes there has never been peace in the world; and long before history began murderous strife was universal and unending." Societies have peace only if they are able to deter the violent tendencies of those that live around them. If we in Singapore have enjoyed an interlude of peace over the last 35 years, it is because we have consistently and constantly paid attention to our defence so that it serves as a deterrence to those who may wish violence upon us.

While violent conflict is the dark side of human nature, there is also a bright and optimistic side to human nature. We have within ourselves, as a universal pattern of behavior, the ability to cooperate with others for the greater good of the community. It is this ability to work together that allows a division of labor. Adam Smith, in his book, "The Wealth of Nations" recognized that the division of labor is what makes human society more than the sum of its parts. He used the example of the pin-maker to illustrate his point. Somebody not trained as a pin maker could probably make only one pin a day. Ten people in a pin factory, could in Adam Smith's days, produce 48,000 pins. Cooperative behavior between people increased the output of their effort many-fold. We are still learning what makes us cooperate as a society and what rules underlie the human capacity to cooperate.

The 20th century gives us some insight into two models of human cooperation. In the first model - communism, individuals cooperated for the greater good of society and individual benefit was secondary. Altruism was to be the motivating force. In the second model – capitalism, individuals cooperated for their individual benefit and the advancement of society was a secondary result. Self-interest was accepted as the motivating force. Altruism and self-interest are driving forces in our behavior. Although humans are capable of great acts of altruism, unless altruism was buttressed by self-interest, the altruism was not sustainable. That is why communism failed. Capitalism triumphed because the basic behavioral pattern in our brains is such that self-interest is a stronger force than altruism.

Politics, my present vocation, is the art of understanding human behavior and the science of making rules for the greater good of society. To succeed, the rules must work within the limits of the brain's intrinsic patterns of behavior. This is the challenge in political leadership and government.

From ancient times, understanding human behavior has been central to civilization. Engraved at the entrance to the temple of Apollo at Delphi is the famous maxim “Know thyself.” For us, in our age, this means knowing our brain, knowing its limits, knowing our genetic heritage, knowing the little bits in our genetic heritage that makes the human brain unique in its ability to contemplate its own self, its own structure and existence, and the meaning of its existence in time, and in the universe. This is what makes us human, and the human species special and different from all other species that preceded us on this earth.

Thank you.