The Impact of High Conflict in Families on the Brains of the Children

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INTRODUCTION

Toxic environments often cause severe problems with the development of children’s brains, their endocrine systems and even their DNA. One usually associates ‘toxicity’ with a poison, or some physical material. However, ‘toxicity’ when we are talking about the brain extends to emotional experiences, and stress.

In August 2009 I attended the World Congress on the Rights of the Child in Halifax. At that Congress I had an opportunity to attend a presentation by Dr. Jean Clinton of McMaster University and Dr. Robbin Gibb of the University of Lethbridge which amazed me. I learned that children’s brains changed when they were exposed to toxic environments. I learned that a high conflict family environment is a toxic environment. And I learned that exposure to these kinds of conditions has a real physical impact on the human brain.

The brain is central to who we are. This sentiment has been repeated and repeated in the research that I have reviewed.

I am a judge with a superior court in Canada. We are responsible for family law matters concerning children in families in high conflict. With my Masters of Social Work I had been exposed to social research on the short and long term impacts of early childhood adversity, but that research was considered by many to be “soft” science”. It was not, therefore, taken very seriously. However, solid scientific evidence measuring the impact on the growth and development of the brain of human beings would, I knew, be taken very seriously. Therefore, I applied to the Canadian Judicial Council for study leave. It was my intention to review the scientific research on this subject with a view to making that science accessible to judges and lawyers. I also wanted to consider a different approach by the courts in family law: one where we would intervene early in the family conflict with appropriate processes and thereby make a positive difference to the brains of the children in those families. Essentially, I was seeking a harm reduction model for the Court.

I knew that the major advances in brain research are fairly recent, largely in the last 10 to 15 years, so I imagined that there would be only a small amount of research on the subject of brain development and the impact of environment on that development. Little did I know that there was a huge and expanding body of scientific research on the impacts of early childhood adversity on the brains, endocrine system and even DNA of human beings. Adversity includes, but is not limited to, conflict in families.

There is no doubt in my mind that the research clearly demonstrates that early social adversity causes changes in the brain structures of children and in their endocrine
responses to stress. One recent study even determined that the DNA of children is impacted.

However, we must ask, so what? If children’s brains are changed as a result of early adversity, why does that matter to the courts?

The research shows that early social adversity is associated with such things as mental illness, drug addiction, criminal behaviour, lack of achievement in school, and degraded adult health outcomes.

The “best interests” of children is the central and driving principle applied by the courts in Alberta and Canada when determining issues important to children concerning custody/access or parenting time/parenting responsibility. Therefore, if there are negative changes in the brains of children which have impacts on the future of those same children, it is my view that the courts must intervene in family conflict as early as possible and ensure that these high conflict families and especially the children receive appropriate assistance.

Judges rightly are concerned that they do not have the skills to deal with high conflict families akin to the skills of psychologists or social workers. However, as judges we can find alternative ways of dealing with these families so as to ameliorate their conflict and its negative downstream effects.

In this paper I start with a basic science lesson, describing the brain, its structures, neurons and how the brain develops. This description is necessarily simplistic. It serves only to assist the reader to understand what the science is telling us about impacts of environment on brain development. The brain is a very complex structure in the human body and we are only beginning to understand it. There is much to do.

As our research equipment becomes more sophisticated and precise, we will be able to look into the living brain to learn even more about it. The development of functional magnetic resonance imaging (fMRI) and other equipment has assisted scientists in the near past few years to learn a great deal. The future holds many wonders.

In this paper I will review first the architecture and development of the brain.

Second, I will address the impact of environment on the normal and natural development of the brain. Specifically, I will review what the scientists call “toxic environments”, experiences and circumstances that make deleterious changes to children’s brains.

Third, I will address the outcomes we can expect from toxic environments.
Fourth, I will review the evidence that the brain can change itself, called neuroplasticity. This phenomenon gives us hope and the *raison d'être* to make changes in our system so as to provide an environment in which the children of our high conflict families will repair and flourish.

Fifth, I ask the question: What can we do about it? It is my hope that, as judges and lawyers, when we understand the permanent and serious impacts that toxic environments can have on children, we will collectively do a much better job of assisting parents in the legal system to nurture their children, and not to hurt them.

Finally, a word of caution. Although the research on the brain is astonishing to a person like myself who is not a neuroscientist, that research is only in its infancy. The brain remains a wonderful mystery and we will learn more and more about it beyond my lifetime. Therefore, what we do know today is subject to further research. Also, as we learn more and more about the brain, we will face ethical dilemmas about how we use that information, in the courts and beyond.

Before I move on to the substance of my paper, I would first like to Dr. Bryan Kolb¹, of the University of Lethbridge and Dr. Jean Clinton of McMaster University.² Dr. Kolb guided me through my research and introduced me to a Scientific Colloquia: *Biological Embedding of Early Social Adversity: from Fruitflies to Kindergarten*. These Colloquia were sponsored in December 2011 by the National Academy of Sciences in the USA and by the Canadian Institute for Advanced Research. It was at those Colloquia that I heard some of the most recent research being conducted in Canada and the United States of America on brain development in the face of early childhood adversity.³

Dr. Jean Clinton is a psychiatrist who is passionate about the impacts of environment on the brains of children and who has encouraged my review of the research. She is also the source of many of my illustrations in this paper which she has shared generously with me.

I also thank Dr. Robbin Gibb⁴, a neuropsychology researcher at the University of Lethbridge who kindly provided me with references and encouraged my endeavour.

I thank Donald Netolitzky, legal counsel, for his editing and lively discussion about the subject of this paper.

Finally, I would be remiss if I did not acknowledge the Norlien Foundation of Alberta and particularly Nancy Mannix. That Foundation has brought together scientists who are concerned about the development of children’s brains and the subsequent behavioural outcomes of adversity. The Norlien Foundation’s attention to this subject initially flowed
from their concern for the sources of addiction. Subsequently, they have concluded that early impacts have negative influences on children that go far beyond addiction. The Norlien Foundation has established the Alberta Family Wellness Initiative which sponsors scientific conferences that explore the environments of children that lead to negative outcomes. The Initiative has a website which I highly recommend for anyone interested in this subject.\(^5\)

I have been encouraged by a wide number of scientists who are trying to ensure that their scientific research finds its way to policy makers. Scientists were encouraged that a judge would be interested and that there were potential positive policy changes that could be made in the courts dealing with family law to ensure that children were not injured by the processes their parents face in our courts.

THE BRAIN – ITS ARCHITECTURE AND HOW IT DEVELOPS\(^5\)

The following discussion is necessarily simplistic. It is my hope that this description of the brain, its architecture and development, will provide a basis for my description of the impact of toxic environments on the brains of children.

The brain is a complex structure comprised of neurons and other important cells. The neurons are organized into specific structures, each one with primary responsibility for a function, such as memory. The brain starts developing early in embryonic development and continues to develop into late adulthood and perhaps beyond. The human brain has specific “sensitive periods”, in which critical parts of the brain develop. Failure to develop completely results in difficulties later in life in many areas. For example, spoken language is readily learned in early childhood. These sensitive periods occur during the early years of the brain’s development, and continue up to about 30 years of age.

Development of the brain and nervous system, as with any part of human development, is guided by the DNA information found in our genes. However, that development is not determined only by the genes, because the genes are expressed in the context of the environment that exists at critical or sensitive periods. That environment impacts on how the instructions in genes are expressed, or in other words, how the instructions given by genes are interpreted for the building of specific proteins which form or guide brain structures.

Our genetic information sets the limits for what a brain can do. Environment then shapes and restricts the possible expression of those parameters.
Here I discuss the architecture (sometimes referred to as the geography) of the brain. I discuss neurons and how they are formed and their purpose. I will then discuss the process of the development of the brain throughout life, emphasizing the early years.

**Architecture**

The human brain is a 3 pound mass of soft tissue inside our skulls which accounts for about 2% of body mass but is not much larger than a large grapefruit. At birth the newborn brain weighs about 350 – 400 gms. Once we reach adulthood, the adult brain weighs about 1,300 – 1,400 gms. Clearly, there is a huge increase.

The brain can generally be divided into three regions: the forebrain, the midbrain and the hindbrain. The brain also contains other critical structures which I shall describe shortly.

The forebrain is the largest and outmost part of the brain.

It includes the cerebral cortex, which is the outer layer of the brain (see Figure 1). This region provides the functions that make us human. It is the centre of higher thought, language and human consciousness that gives us the ability to think, reason and imagine. It controls sensory and motor functions, language, imagination, planning, reasoning, and consciousness. About 75% of the hundred billion neurons in the human brain are located in the few millimeters of grey matter of the cortex.

Figure 2 shows the major geographic areas of the brain: the Brainstem, the Cerebellum, and the four lobes of the cerebral cortex: the frontal lobes, the parietal lobes, the temporal lobes, and the occipital lobes.

The bumps you can see on the cerebral cortex are called gyri (one is a gyrus), and the grooves are sulci (one is a sulcus). The larger sulci which divide the lobes of the brain are called fissures or may be identified as a specific sulcus (see Figure 211).

The frontal lobe of the cerebral cortex is associated with reasoning, motor skills, higher level cognition and expressive language.
The parietal lobe is associated with processing tactile sensory information (pressure, touch, pain).

The temporal lobe is the location of the primary auditory cortex, associated with interpreting sounds and language. The temporal lobe is also the location of the hippocampus, among other things, which I discuss later.

Finally, the occipital lobe is associated with interpreting visual stimuli and information. This is the area that receives information from the eye.

This description is simple, of course.

The brainstem is comprised of the hindbrain and the midbrain. It connects the brain with the spinal cord and is responsible for many vital autonomic functions such as heart rate, breathing and blood pressure.

The cerebellum, which is shown in Figures 2 and 3, is responsible for our balance system – the inner ear, sensory nerves, and auditory and visual systems, and tracks the location of our body parts relative to one another.

The internal brain, under the cortex, in the temporal lobe is known as the limbic system comprised of four main structures: the amygdala, the hippocampus, the limbic cortex and the septal area. The limbic system is thought to be the part of the brain through which our senses are processed and important for control of emotional responses including aggression.

The hippocampus, which is part of the limbic system, is the part of the brain that is involved in memory forming, organizing, and storing. It is a very old part of the cortex.

The hippocampus is responsible for relaying information to the cortex for long-term storage and retrieving it when it has to be recalled. It is a limbic system structure that is particularly important in forming new
Figure 4: The Limbic System (amygdala) memories and connecting emotions and senses, such as smell and sound, to memories. The hippocampus acts as a memory index by sending memories out to the appropriate part of the cerebral hemisphere for long-term storage and retrieving them when necessary. As you can see from Figure 5, the hippocampus is located in both brain hemispheres.\(^{15}\)

The amygdala is an almond shaped structure in the brain. There are actually two amygdalae shown in yellow in Figure 5 and in red in Figure 4. They are located close to the hippocampus in the frontal portion of the temporal lobe. The amygdala is also a limbic system structure that is involved in many of our emotions and motivations, particularly those that are related to survival. The amygdala is involved in the processing of emotions such as fear, anger and pleasure.\(^{16}\)

The amygdalae are essential for us to feel our emotions and to sense or discern emotions in other people. They are particularly important for discerning fear in other people and for stimulating fear in ourselves. The amygdalae are important for determining what memories are stored and where the memories are stored in the brain. It is thought that this determination is based on how huge an emotional response an event invokes.\(^{17}\)

These, then, are the major regions of the brain which will be referred to in the balance of this paper. It may be helpful to think of them in layers, as that is how the vertebrate brain may have evolved. At its base and core are the parts that control automatic functions. Above that are the parts that administer instinctual and emotional behaviour, and correlate that to experience. Last, are the increasingly sophisticated sensory interpretation and learning areas, which in humans have developed to allow sophisticated reasoning and expression. Nevertheless, those higher cortical functions are still dependent on and intimately involved with older more automatic, instinctual, and emotional components of the brain’s structure.

**Neurons**

The adult brain is composed of about 90 to 100 billion nerve cells, or neurons. Neurons are the basic building blocks of the brain and nervous system and are responsible for information processing. Simply put, without them we do not have a brain.
A neuron is made up of a cell body (which contains the DNA), dendrites and an axon with branches [Figures 6 and 7]. Dendrites gather signals, while the axon carries signals to a destination.

Each neuron is different. Neurons vary in size, shape, the number and length of dendritic branches, the length of the axon, and the number of branches on the axon.

Our brain functions by communication from neuron to neuron. Generally, that communication occurs by the dendrites receiving electrical impulses from a nearby axon. The impulse received by the dendrite is passed along the neuron to its axon, which then passes the electrical impulses to the dendrites in the next neuron. Neuron Thereby the neurons in the brain (and other parts of the nervous system) communicate with other neurons forming neural networks.

The communication from axon to dendrite occurs across a synapse or gap. Just to give an idea about how complicated our brains are, each cubic millimeter of cerebral cortex contains roughly 1,000,000,000 (that is one billion) synapses. There are about 100 trillion synapses in our brains.

Figure 8 shows graphically the relationship between the signal sending neuron (axon) and the recipient neuron (dendrite) via a synapse, which is a small physical gap between the two cells.

How does the electric impulse get across that gap? This is done through a biochemical process called neurotransmission. When a signal passes along a neuron’s axon to its end, that impulse causes the axon end to release neurotransmitters (chemical messengers). These then flow from the axon across the gap, and are detected and received by a dendrite of the recipient neuron (the postsynaptic neuron).
There are many different neurotransmitters. They have two general effects on the postsynaptic neuron. Some neurotransmitters ‘excite’ the downstream neuron, and cause it to send more frequent signals down its axon. Other neurotransmitters inhibit the receiving neuron from sending signals down the axon. These two processes work together, and whether a neuron signals or not is a balance of the inhibitory and exciting signals it receives via neurotransmitters. This process is critical to our functioning.

Neurotransmitters are not the only chemicals that excite or inhibit neurons. Drugs, hormones, and other signals do the same thing.

Figure 9 represents the synaptic gap, showing the neurotransmitters ready to be deployed across the synaptic gap. One can only imagine how important it is for all those neurons to fire correctly.

I now turn to a discussion of the development of the brain.

**Development of the brain**

Up until relatively recently, it was believed that the brain finished developing at birth. However we now know that the brain continues to develop after birth into adulthood, possibly throughout a person's life. This development involves neurogenesis. Neurogenesis is the process by which the brain and nervous system develop through the creation and interconnection of neurons.
The first signs of brain development in an embryo occur very early (see Figure 10). In the third week of embryonic development, the neural tube, which becomes the nervous system, develops.

Throughout the embryonic period, which lasts about seven months, the organs, including the brain and nervous system, continue to develop. During this period the development of the embryo is vulnerable to disruption.  

The sulci and gyri appear in the brain at about 5 months before birth and take at least the first year to develop fully.

Early in the development of the brain its cells are simple and unspecialized. However, very soon those cells become neurons and the neurons grow axons and dendrites. As early as the 15th week of gestation, dendrites and axons are formed. After the 25th week of gestation, there is a large increase seen in the development of axons and dendrites. By the time a baby is born it will have about 120 billion neurons in its brain. You will note that this is more than in an adult human being.

Neurons cannot communicate without synapses. Synaptogenesis is the development of those synapses. After birth there is a significant increase in the number of dendrites and axons which results in a major increase in the number of synapses between neurons.

A process called sprouting is the targeted growth of the axons of neurons toward the dendrites that are nearby and sometimes not so nearby. There is evidence to suggest that some neurons extend all the way across the brain. Different “geographic” areas are
connected to other areas with this mechanism. Figure 11 shows the development of neurons from birth to 24 months. The neurons grow dendrites, axons and interconnections at a rapid rate after birth.\(^{29}\)

As the neurons develop through sprouting dendrites and axons, more and more connections are made. Those connections become more complex. Figure 12 shows how the complexity in connections develops through experience.

![Figure 11: Development of Neurons](image)

Babies are born with more than the adult complement of neurons. Then in early infancy those neurons rapidly develop connections to other neurons. Through this process the brain develops the complex geography I have described above. Through childhood and the teenage years, the neurons that are firing (being used) consistently develop strong connections. It is commonly said by neuroscientists that the neurons that fire together wire together.

![Figure 12: Experience shapes neurons](image)

Research has demonstrated that neurons which are not in use die. In other words, if the neurons are not being used through viable connections and synapses, they disappear. This is called "use it or lose it".

The excess of neurons found in an infant, therefore, disappear gradually until the complement of about 90 to 100 billion neurons remains in adults. This process which occurs rapidly in adolescence is called “pruning”. “Brain Cells develop connections over the first 2 years [after birth] and then they are sculpted actively the rest of your life!” \(^{31}\)

Pruning occurs largely in teenage years. It is no wonder that we perceive teenagers to be somewhat unpredictable and sometimes “off the wall”. This behaviour is normal, as there is a major reconstruction occurring in their brains.
Myelination of axons

There is another process, myelination, which happens in our brains during those developmental years which causes more rapid transmission of signals inside the brain. Myelination causes the formation of a special coating around the axon called myelin. This is a kind of ‘insulation’ that helps signals move along the axon more quickly.

Myelin is created by non-neuron cells located in the brain called glial cells. Specialized glial cells called astrocytes help guide developing neurons toward their synaptic targets. Other glial cells called oligodendrocytes form myelin sheaths around the axons of the neurons. An axon coated with myelin can fire much faster and more efficiently than a neuron without the myelin sheath, as much as 300 times faster. Myelination continues into the teens. We have heard the expression grey matter and white matter. The grey matter is largely constituted of cell bodies of neurons and the white matter comprises axons connecting to other neurons. It is the myelin sheath around the axons that makes the matter white.32 Living brain cells in the ‘grey matter’ are actually pink because of the blood supply to the brain.

One can guess from the above description of the development and growth of neurons, that environment may play an important role. One would be correct.

ENVIRONMENT'S IMPACT ON BRAIN DEVELOPMENT

In this discussion, we will explore some of the science that has demonstrated that genes and environment interact and how this occurs. We will begin with a discussion about the nature versus nurture debate.

Nature versus Nurture

Social and physical scientists for generations have debated whether we are born with certain personality and characteristics, or whether we learn them. This debate was commonly called “nature versus nurture”; whether we, as humans, are determined by our genetic ‘programming’ or are shaped by our environment.

The scientists at the Colloquia in California33 were very clear: that debate is over. Now scientists understand that there is a complex relationship between both. Our brain, including its flexibility and capacity to learn, is encoded in the genes in our DNA. Those capacities are the product of our evolution, and how nature has selected for features and capabilities that are helpful. How those genetic potentials actually develop is a consequence of environment. The gene comprises the nature part of development. The environment is the nurture part that influences the expression of the gene.
The brain is not fixed at birth. It is plastic. Experience shapes it. As we experience life, first as children and then as adults, the brain changes: synaptic connections become strengthened by experience, or disappear when not used, synaptic receptors become more or less receptive to neurotransmitters.\textsuperscript{34}

As a result of the interaction between nature and nurture, the brain changes.

\textit{Environment and genes interact}

It was only in this century that scientists mapped the human genome.\textsuperscript{35} Therefore, we are at the beginning of a new era in the understanding of humans and their bodies and brains.

There are many studies that have set out to try to determine whether particular behaviours in adults are based on genetics or on the environment. What those studies tend to show is that it is not a simple relationship between genes and specific behaviours, but rather that the behaviours are influenced by the environment in which the child grows up. Identical twin studies have been done, as have adoption studies.\textsuperscript{36}

It has been found that genes have more to do with personality than we first thought. Activity level, aggression, and effortful control during early years are all moderately heritable (predicted by a gene). However, how a particular gene interacts with its environment is a better predictor of behaviour. Some genes have high heritability and some do not. Heritability is definitely context dependent.\textsuperscript{37}

It is nature \textbf{and} nurture that shape our minds.

Science has generally not yet identified specific genes associated with specific behaviours. However, research has shown predictability of human behaviour for a combination of specific genes expressed in certain environments.

Many genes turn on or off depending on the immediate environment. Sometimes environmental signals are chemical. In fact, there is a well-known example in our recent history of chemicals influencing the development of human beings \textit{in utero}, that is, the thalidomide babies. The drug (thalidomide) taken by the mothers during the development of the foetus influenced the gene expression with respect to the baby’s limbs. If that chemical was present at the specific time at which the fetal arms and legs are organized the genes were not able to express properly the instructions to create those structures. This was during a ‘sensitive period’ for limb formation. Thalidomide had no effect on the mother’s limbs because the ‘limb structure’ genes had already done their work and the final structure was formed.
Alcohol can affect fetal brain development in this way. Among other things, it affects proper operation of genes that organize fetal brain development, creating a highly characteristic set of physical and behavioural abnormalities known as Fetal Alcohol Spectrum Disorder.

Some environmental factors can affect genes in a way that lingers, lifelong, or even into additional generations. Somehow the environment can short-circuit evolution (genetic code) and pass along new traits in a generation and even over generations. These changes include those that organize the development and structure of the brain.

The question is, how does this happen?

Scientists have discovered that areas of DNA can be ‘tagged’ with minor chemical alterations. These tags generally turn off genes that are tagged. Study of this tagging process is a fairly new science, epigenetics. These tags, once added, are inherited by any new cells produced when a cell divides.

The DNA of a newly fertilized egg, a zygote, has almost no tags. As that zygote divides to form an embryo, areas of DNA are tagged and their genes are turned off. This is one way that embryonic cells become more and more specialized.

Some tags are added or removed during a person’s lifetime as a consequence of environmental factors. Epigenetics has demonstrated that this is a mechanism in each cell which influences the expression of genes. Epigenetics has discovered changes to gene expression that are heritable, but where the DNA is not changed. Although the DNA is not changed, the characteristics of particular cells are.

![Romanian children in orphanages](image)

Those changes may last for the life of a particular cell or may be passed on for generations.38

It was not understood until recently that the emotional environment of an infant could influence the development of its brain. However, an unfortunate human laboratory was found in Romania. There, as a result of the President's push to have more children born in his country, many babies were placed in orphanages. Women were prohibited from using birth control or having abortions. Consequently, they had babies which the families simply could not afford. Many families placed their unwanted babies into
orphanages where they were neglected because there were simply too many babies for staff to care for with love and affection. The caregivers were able to feed the babies only quickly, putting bottles in their mouths, not holding the babies to feed them, simply leaving them to lie in their cribs. Some of these babies lived in that state for months and some for years. Many of the babies adopted by families in Great Britain and United States of America, although they appeared beautiful, did not thrive. Consequently, brain scientists studied these children's brains to try to find out what caused the developmental difficulties these children faced. Investigators learned that the brains had not developed. Severe neglect caused the brains of these children not to develop physically. Images of their brains show a remarkable lack of development of the actual structures of the brain.

Their physical brains were small. The Romanian babies are a dramatic example of what can happen to the physical development of a human being’s brain because of environmental impacts, nurture affecting nature.

Figure 14 shows images (functional magnetic resonance imaging (fMRI)) of a normal child's brain and one of a child who has been extremely neglected. As you can see, the physical structure has failed to develop normally.

Scientists now know that the more a system or set of brain cells is activated, the more that system changes in response: the stronger the repetitions, the stronger the memory.

Figure 14: brain images of normal/extremely neglected children

Children in adversity are not provided the environment in which their brains can develop to that child’s potential.

In the late 1950s and early 1960s, there were animal experiments, usually using monkeys, which had demonstrated that there was greater cortical development when the animal was put into a stimulating environment as opposed to one in a drab, impoverished environment.

Studies found that infants (this largely in Romania) who are institutionalized for less than six months in the orphanage achieved a normal IQ score. If they were institutionalized over six months, the scores decreased depending on how long the children were in those orphanages. If the children were not adopted before age 8, and
they had suffered a lack of cognitive stimulation, it meant that the child was not likely to learn a language. These children had not learned language because they had not encountered the stimuli to develop that skill during the genetically programmed sensitive period.

The most astonishing thing in my mind was that when the researchers compared nutrition to social deprivation, they found that the length of time a child was socially deprived was more predictive of later delays in intelligence and social functioning than the lack of nutrition. The research done in this area was carried out fairly early in brain research. Monkeys when given an option of associating with a wire monkey covered in soft cloth that could not provide food, and a wire monkey not covered in the soft cloth that did provide the food (a bottle was wired into the wire monkey), an infant monkey always chose the wire monkey covered in the soft cloth.

Brains are more dependent on social contact than food.

However, the one thing that was dependent on nutrition was myelination. I discussed above the importance of myelination with respect to the speed with which neurons can transmit impulses. Myelination begins at about seven months prenatal and continues well into adolescence.

The examples cited above are dramatic. One may ask if lesser neglect has an impact on children’s brains. The evidence suggests that it does.

**Behaviour: environment and genetic expression**

Human beings are usually born with something called temperament. It is a predisposition to certain kinds of personality and represents early-appearing, biologically-grounded tendencies in terms of interaction with its environment. Scientists have been able to differentiate different patterns relating to temperament which can be measured during the first year of life. Temperament sets the stage for attention and self-regulation of behaviour. Genes have a role in establishing the child’s temperament. Activity level, aggression, and effortful control during early years are all moderately heritable. However, it appears that environment interacting with a gene is a better predictor of behaviour. Some genes have high heritability and some do not. Heritability is definitely context dependent.

Unlike most other mammals, human beings have a very long period of helplessness. However, this period of helplessness is essential to attain full brain maturation and development. The human brain appears to be more complex than other mammal brains and certainly than other animal brains. In order to attain full brain maturation, the human infant must be cared for by its caregiver for a very long period of time. During the early
years of a child's life it forms attachments to his caregivers. These attachments are critical for brain development. The responsiveness of the parent (caregiver) shapes the child's attachment which is reflected in the structures of the brain. As the infant learns, it sculpts its brain. If it is in a poor environment which offers little guidance as to social behaviour or puzzle-solving, then the neurons’ interconnections, dendrites and axons, do not develop as much complexity.  

During the early years of a child, the caregivers' responses to the infant's temperament are crucial, particularly when a child is highly reactive and distressed (about 15% of babies). Research has demonstrated that these infants tend to develop into adolescents with high rates of negative emotions, shyness and distress. However, that is not an inevitable result, these responses are developed as reactions to their environment. These less advantageous results can be modulated through the environment, that is, through the way that the caregivers respond to the child.

The infant attachment to its caregiver forms the basis for the young child's ability to interact with the world around it. Generally speaking, if infants form secure attachments, they will be able to form secure attachments as adults and will have better regulation of emotions.

Rhesus monkeys raised in a lab in Maryland showed changes in behaviour when they were raised or not raised with a mother. Some of the monkeys did not spend any time with their mothers and tended to attach to peer monkeys. As adults, these monkeys are predictably more aggressive than their peers who were raised with their mother. The unattached monkeys also demonstrate more difficulty attaching to other adult monkeys and their sexual behaviour is difficult. Further, the isolated monkeys showed more of a propensity to consume alcohol. Their serotonin levels were unusual, and they are more fearful and had unusually high levels of cortisol (a stress hormone). When given brain scans, their brains did not show as much neural activity as the mother raised monkeys.

The researchers found that when the mothers abused their infants, those monkeys appeared like the ones not raised by a mother. Hence, having an abusive mother is just as bad as no mother at all.

Further, when epigenetic ‘tags’ on the DNA were examined, the monkeys that were not mother-raised showed an increase in ‘tagging’ of the DNA. A full 1/5 of the chromosomes were ‘turned off’. Further there was a significant difference in serotonin transporters. With the more recessive gene for serotonin transportation, if the mother was neglectful this accounted for negative outcomes.
More on epigenetics

Epigenetics, a relatively new science (about 20 years old), has studied changes in human beings which do not involve changes to the genetic code but changes that do get passed along from generation to generation. It appears now, and is well-established, that there is another mechanism in our cells that affects the expression of genes. It is the epigenome. Although the genes themselves cannot be changed from generation to generation, the epigenome can and it does impact the expression of the genes from generation to generation.  

This is best expressed as follows:

These patterns of gene expression are governed by the cellular material – the epigenome – that sits on top of the genome, just outside it (hence the prefix *epi*-, which means above). It is these epigenetic "marks" that tell your genes to switch on or off, speak loudly or whisper. It is through epigenetic marks that environmental factors like diet, stress and prenatal nutrition can make an imprint on genes that are passed from one generation to the next.

It is also clear from this research that gene expression can be influenced in a single generation by the environment in which that gene is giving instructions for cellular development.

Research has been done on fruit flies demonstrating that a change in temperature can change the eye colour of the offspring. More important, that change in eye colour is passed from generation to generation through epigenetic mechanisms. Therefore, environment affects inheritance.

The underlying DNA does not change. Rather, a mechanism responsible for turning genetic expression on and off appears to be involved.

Studies on mice have shown that pre-natal stress carries an increased risk of premature birth, low birth weights, and increased stress response of the infants. However, opposite to this, enriched social environments also have an effect. The hippocampus of the brain is affected by the environment. Further, there is a trans-generational effect. This is explained by epigenetic effects or tags that are carried from one generation to the next. The slate is not wiped clean with subsequent offspring.

The reason this is important in the context of this paper is that the environment to which children are exposed, including chemical environments such as alcohol or drugs while a
foetus, and perhaps children's exposure to violence or parental warring, may have an impact not only on those children but on the children of those children.

Recent studies in mice have suggested that stress on fathers may be passed along to their offspring. Male mice were exposed to chronic stress which was passed along to their offspring (but only when the offspring were produced through natural reproduction). This has led to more interest in studying this phenomenon in human beings.\(^{55}\)

Another recent study has suggested that the number of stressful events in pregnancy experienced by a mother may increase the risk of behavioural problems in children. Those stressful events included things such as financial and relationship problems, job loss, a difficult pregnancy and other major life stressors. The study found that two or fewer stressors during pregnancy are not associated with poor child behavioural development.\(^{56}\) This research is only the beginning of understanding mechanisms of stress during pregnancy and how it affects the developing baby.

This science is new and will provide interesting explanations in the future as to inherited characteristics. Epigenetics suggests that life-long and intergenerational 'programming' exists, including characteristics such as behaviour, emotion, and personality. This means environment has a lasting impact on children and their offspring. The challenge will be in determining what epigenetics does or does not account for in behaviour of human beings, which behaviours are learned and then preserved via neuron interconnections, and what is a combination of both.

Fortunately, because of brain plasticity, even where there has been stress during pregnancy, a nurturing environment after birth can have a positive impact on the development of a child.

### OUTCOMES

There has long been powerful evidence that adults who experience prolonged exposure to highly stressful environments that trigger “fight or flight responses”, such as combat, exhibit permanent and highly predictable alterations to their behaviour and psychological state.\(^{57}\) These deleterious changes occur without any associated physical trauma. Given that fact, it is not surprising to learn that children who are exposed to high levels of stress may undergo similar effects.

Toxic environments are stressful for children.
The evidence about outcomes from those toxic environments arises from research on the physical brain and social research on the impacts of adverse environments on large cohorts of a population.

Numerous social science studies over the years have demonstrated that children who are raised in poor or toxic environments have poor outcomes as adults in the areas of adult health\textsuperscript{58}, drug addiction, mental illness, crime and relationships. Brain research now demonstrates the underlying physiological mechanisms that explains these behaviours. For example, studies in non-human animal models suggested that early stress may alter portions of the pre-frontal cortex associated with self-regulation of social – emotional behaviour.\textsuperscript{59} In human studies, the right orbitofrontal cortex (among other parts of the brain) of children who were verified victims of physical abuse was smaller than those of non-abused children.\textsuperscript{60}

In many circumstances, ethical restrictions prohibits us from using human beings for experimentation. As a consequence, our knowledge about brains often comes from animal studies from which we can extrapolate what happens in the brains of humans. Ironically, comparison of sequenced DNA genomes has shown that there is not a huge difference, genetically, between us and rats. Furthermore, the general anatomy of vertebrate brains, particularly in mammals, is very highly co-related. Therefore, we do rely on animal experiments to predict things that can happen to human beings when exposed to toxic environments. We cannot ignore these experiments. Further, the results in animal models are echoed where there is analogous data from human population studies.

There is little doubt that parent-child relationships are critical in brain development (Kolb & Gibb 2011).

Above we discussed the impacts on the brain suffered by children in Romania. This provided an unfortunate human study which has garnered a great deal of evidence about what happens to the brains and behaviour of people who were orphans in that country. Research shows that maltreatment (emotional, physical, sexual, neglect) of children and adolescents can result in mood and anxiety symptoms. Research on these kinds of subjects identifies evidence of altered catecholamines\textsuperscript{61} and hypothalamic-pituitary-adrenal (HPA) axis activity. This is so because elevated levels of catecholamines and cortisol may lead to adverse brain development. These effects are a result of loss of neurons, delays in myelination, developmentally inappropriate pruning, and inhibition of neurogenesis\textsuperscript{62}

Experience throughout our lives impacts our brains, sometimes positively, sometimes negatively. For example, animals raised in severely deprived environments such as darkness, silence, and social isolation clearly show retarding of brain development.\textsuperscript{63}
A positive example can be found in an interesting study conducted by Kolb & Gibb (2010) which demonstrated that infant rats which were brushed with a small brush for 15 minutes three times a day for 10 to 15 days beginning at birth showed enhanced skilled motor performance in spatial learning as well as changes in synaptic organization across the cerebral cortex. These rats demonstrate that simple tactile stimulation leads to an increase in the production of a neurotrophic factor (FGF-2) in both skin and the brain. Scientists have also shown significant neuronal changes associated with environmental enrichment. These changes include increases in brain size, cortical thickness, neuron size, dendritic branching, spine density, synapses per neuron, allele numbers and complexity. These changes are demonstrated for adults and juvenile rats.

Further, mother rats placed in enriched environments gave birth to infant rats that also showed changes in their neurons. Although Kolb & Gibb tell us that the physical changes to the neurons are different depending on the age of the rat, nevertheless, all of the changes in response to the complex environment lead to enhanced cognitive and motor functions.

Kolb & Gibb concluded that early experiences have a powerful effect on brain organization both during development and in adult hood. That effect can be positive or negative.

Scientists have shown that in rats, maternal-infant interactions have a critical impact on many behavioural and somatic differences. That interaction impacts on the development of the hypothalamic-adrenal stress response and a variety of emotional and cognitive behaviours in adult hood. The effects of differing degrees of maternal care are broad. Kolb & Gibb stated that "there is an enormous literature collected over the past 60 years showing the effects of stress on brain and behaviour in adults". They discuss perinatal stress in infants as well. Both gestational and infant stress apparently predisposes individuals to a variety of maladaptive behaviours and psychopathologies.

Prenatal stress has been found to be a risk factor in the development of schizophrenia, ADHD, depression and drug addiction. Further, experiments with lab animals showed that stress "produced behavioral abnormalities such as elevated and prolonged stress response, impaired learning and memory, deficits in attention, altered exploratory behaviour, altered social and play behaviour, and an increased preference for alcohol" (Kolb & Gibb 2011 citing several other studies).

Experience "gets under the skin" early in life, and does so in ways that affect the course of human development. Heart disease, diabetes, obesity, depression, substance abuse, school success, premature mortality, disability at retirement,
and accelerated aging and memory loss all have determinants in early life (Harkonmaki et al., 2007). The list of research goes on.

But, is the impact of environment completely determinative of the behaviour of the humans exposed to that environment? A question that I have asked for many years is: “Why do some children do so poorly in bad environments but other children, even in the same poor environments, do well?”

At the Colloquia, I learned that there are genetic differences in the way humans respond to their environment. For example, a person born with two identical low-efficiency variations of a gene that encodes a serotonin transport function will predictably be more likely to suffer depression, among other things, in late teens and adult hood. Serotonin is one of the neurotransmitters that carry information across the synaptic gap from neuron to neuron. If a child with those genes is exposed to a toxic environment, its risk of depression goes up.

However, if a child is born with at least one gene that provides for high efficiency serotonin transport, then that child can live in the same poor environment with no ill effect. The astonishing thing to my mind is that if the child born with the ‘low efficiency’ genes is put into a rich environment, the prediction for depression decreases dramatically. Apparently, that child can do even better than the child born with ‘high efficiency’ genes. Environment will impact on the ways those genes are expressed.

Although a detailed understanding of how the brain operates, that is, how the ‘hard wiring’ we receive via our genetic inheritance is impacted by environmental experiences, is still to be characterized, there is no doubt in my mind that many behaviours and psychological states will be identified as having a neurological and neuropsychological origin. In other words, these will turn out less to be ‘choices’, than the consequences of how our genetic character interacts with our environmental history, including our social experiences. This will extend not only to emotion and mood, but also attention and higher level executive functions.

This combination of genetics and environment not only impacts on brains, however, these factors also affect our endocrine (hormone) system and our very DNA.

I referred above to the impact on the endocrine system, that is the role that cortisol may play in intellectual and academic impairments. Our DNA is also impacted.

A telomere is a region of repeated nucleotide sequences located at each end of a chromosome (a molecule of DNA). Telomeres indicate the end of the chromosome and
protect the chromosome from deterioration or from fusion with other chromosomes. In that sense, telomeres operate like the plastic ends of shoelaces which prevent the shoelace from unraveling. Telomeres change with age. As cells divide the telomeres erode, and become shorter. This is an anti-cancer mechanism, as it means any cell in the body can only divide a certain number of times before its telomeres ‘erode away’, causing the chromosome degradation. In this way telomeres are a kind of ‘molecular clock’, that marks biological rather than chronological aging.

However, changes in telomere length have also been associated as an important marker of stress. While the authors of this study caution against a simplistic measurement of telomere length as an indication of aging, they suggest that measurements repeated over time in one individual may determine whether stress impacts on the typical length of telomeres in that individual. Using a carefully selected study sample, the researchers collected DNA samples (buccal swabs) when the children were five and 10 years old respectively. For the purposes of this study, the researchers assessed three kinds of violence experiences the children in the study had experienced between ages five and 10 years: exposure to domestic violence between the mother and her partner, frequent bullying, and physical maltreatment by an adult. This behaviour, of course, was long-term and not situational. The results showed that exposure to violence was associated with telomere change in childhood. This was particularly so for cumulative exposure rather than physical maltreatment alone, that is, children who were exposed to multiple forms of violence experienced the fastest telomere erosion rate. The study provided evidence that childhood stress is related to telomere erosion over time and that the erosion occurs at the same time as the children are experiencing the stress.

While it does not suggest a mechanism for how telomere length is affected by exposure to violence, this telomere study is important because telomeres can predict health outcomes. In fact, telomere measurements in adults are now offered as a diagnostic tool to monitor health and predict disease risk.

**BRAIN PLASTICITY**

The good news is that our brains are plastic.

Neuroplasticity relates to the ability of the brain to change, to forge new pathways and to change the function of a set of neurons where that is required for the human to function. The concept of neuroplasticity has been understood for a long time – but not by that name. It refers to the processes by which brains are altered when the person is exposed to the environment around it – both negative and positive. We have learned that toxic environments create damage to brains (among other things).
Neuroplasticity is good news because a positive change in children’s environments can produce a positive change in their brains (among other things). We can make a difference.

At one time, we thought our brains were like machines with each part set for a particular task and if that part of the brain was damaged, then we would never be able to do that function:

Descartes's idea of the brain as a complex machine culminated in our current idea of the brain as a computer and in localizationism. Like a machine, the brain came to be seen as made of parts, each one in a preassigned location, each performing a single function, so that if one of those parts were damaged, nothing could be done to replace it; after all, machines don't grow new parts.

This is a simplistic concept which is wrong in many respects. We now know that when the brain develops in utero, after birth and throughout childhood, the environment plays an important role in shaping that brain. Some of that shaping is beneficial and some is harmful.

In The Brain That Changes Itself, Norman Doidge describes many situations where parts of the brain of specific individuals did not function and how through appropriate stimuli, the brain changed its networks of neurons and functions of groups of neurons to perform functions that had been damaged, for example, from a stroke. Doidge, for instance, discusses the work of Mark Rosensweig of the University of California at Berkeley who studied rats in stimulating and non-stimulating environments. When he examined the brains of those rats post-mortem, he found that the brains of rats that had been in the stimulating environments were heavier than the brains of rats that had been in the non-stimulating environments. Those brains also had more neurotransmitters and had a better blood supply. This demonstrated neuronal plasticity. The environment had made a change in the brains of those rats. The brain was plastic.

We now know that our brains continue to be influenced by the environment throughout our lives. Doidge gives numerous examples of where a damaged brain can be trained to “go around the damage”. Literally, other parts of the brain can learn a new function with appropriate stimulus.

As I said above, children who were taken out of poor environments and put into good environments have also demonstrated changes. These changes are manifest in the children’s behaviour, just as the toxic environment of their parents conflict has been manifest in negative behaviour.
I will leave it to the reader to obtain and review this book on neuroplasticity, but it is a convincing analysis of the power of the brain, when it is exposed to the appropriate stimuli, to change for the positive. This text is also written in a user friendly way.

**SO WHAT CAN COURTS DO ABOUT IT?**

When we are dealing with families in conflict, the very nature of their children’s brain plasticity assures us that if we can intervene soon enough, those children can recover and lead healthy lives.

One must be cautious about extrapolating the research that has been done, given this is a new area for investigation and much research involves animal models. Nevertheless the research that I have reviewed on physical impacts to the brain and endocrine systems of human beings substantiates the social research that has been conducted for decades. I have often heard criticism about the social research because it was not done following "proper scientific methods". That is, of course, partially valid, because population studies can usually only correlate factors with results, and not prove ‘cause and effect’.

Now, as physical brain research is conducted, that research is supporting many of the findings of earlier social scientists. Further, it provides mechanisms that explain those observed behaviours, and allows physical observation of how stimuli lead to results.

From my research, it has become evident to me that children raised in toxic environments often inherit severe problems in their brains, endocrine system, and even modification to their DNA.

It is my view that the adversarial process followed in the courts across this country exacerbates the conflict in families. We, in the courts, contribute to an even more toxic environment every time we resort to the traditional adversarial process. Every time there is an application before us, that application requires the parents to take at least competing, if not opposing views. By its very nature, a family court proceeding is a conflict.

When we ask for parenting assessments to assist us, as trial judges, to determine the best interests of children, we are adding to the conflict between the children’s parents and the consequent toxic environment in which the children are being raised. Those assessments are a contest by the parents as to who is best suited to have the major role in the family.
Therefore, what can we do, as courts, to ameliorate the conflict we find among the parents before us? How much better would it be if we could direct these families very quickly to trained resources which could help them? What if we could change our processes to ameliorate conflict rather than exacerbate it?

It is not my intention in this paper to be prescriptive. Rather, it is to invite members of the judiciary and lawyers to consider different ways to do things when it comes to family law. What we are doing does not work. Children are being damaged.

However, I believe we, as judges, can make a difference in the lives of children and in their future as adults when we enable those children to grow up in positive environments. Even though the children have already been exposed to conflict before their parents first come to court, an early intervention on our part can help.

Therefore, I invite a dialogue amongst the judiciary, the legal community, and the social science community to find appropriate ways as a system to avoid as much conflict as possible for the children that we serve. Let us find ways, as individual judges and as a legal system, to improve the lives of children that come before us, by ameliorating rather than exacerbating the conflict to which those children are exposed.

POEM

**Child silently praying to warring parents**

I hurt  
My soul hurts  
My very DNA hurts  
How can you hurt me …  
If you love me?
High Conflict and Brains

October 2012

1 [Ph.D. (Pennsylvania State University), M.Sc. (University of Calgary), B.Sc. (University of Calgary)]; Department of Neuroscience, Canadian Centre for Behavioural Neuroscience, University of Lethbridge
2 [B. Mus, MD FRCP], McMaster University and Children’s Hospital, Offord Centre for Child Studies, Council for Early Child Development
3 Unfortunately, the papers from those Colloquia were not published as I wrote this paper.
4 [Ph. D., M. Sc., B. Sc. (University of Lethbridge)],
5 http://www.norlien.org/
6 A very good graphic presentation about the architecture of the brain and neurons developed by the University of Bristol can be found at: www.youtube.com/watch?v=9UukcdU258A&feature=related
7 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 2: How the Human Brain Works
8 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 2: How the Human Brain Works
9 Kendra Cherry, "Introduction to the Brain – The Cerebral Cortex", online: About.com, Image by the Substance Abuse and Mental Health Services Administration (SAMHSA)
10 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 1: Brains and Minds, Evolution and Development
11 Dr. Jean Clinton, personal communication permission to use
12 Kendra Cherry, "What is the Limbic System", online: About.com Guide <http://psychology.about.com/od/biopsychology/ss/brainstructure_8.htm>
15 Dr. Jean Clinton, personal communication permission to use
18 Dr. Jean Clinton, personal communication permission to use
19 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012), Lecture 3.
20 Dr. Jean Clinton, personal communication permission to use
21 Dr. Jean Clinton, personal communication permission to use
22 For a more detailed description of the parts of the neuron and the function of each part, see: Kendra Cherry, “Structure of a Neuron”, online: About.com <http://psychology.about.com/od/biopsychology/ss/neuronanat.htm>
23 Dr. Jean Clinton, personal communication permission to use
25 Dr. Jean Clinton, personal communication
26 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012), Lecture 3: Development of the Human Brain.
27 Dr. Jean Clinton, personal communication
28 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 3: Development of the Human Brain.
29 After birth and up until at least middle-age, we know that there is neurogenesis in the hippocampus which involves memory: Nelson, ibid.
30 Dr. Robbin Gibb, University of Lethbridge: from Dr. Jean Clinton, personal communication
31 Dr. Jean Clinton, personal communication
32 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 2: How the Human Brain Works
33 The papers unfortunately had not been published at the time this paper was written.
34 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 3: Development of the Human Brain
35 The human genome project was completed in April 2003 with 99% of the human genome sequence to 99.99% accuracy. The project began in October 1990.
36 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 14: Myths and Realities of Heritability
37 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 14: Myths and Realities of Heritability
38 Epigenetics: DNA Isn’t Everything, ScienceDaily (Apr. 12, 2009): A certain laboratory strain of the fruit fly Drosophila melanogaster has white eyes. If the surrounding temperature of the embryos, which are normally nurtured at 25 degrees Celsius, is briefly raised to 37 degrees Celsius, the flies later hatch with red eyes. If these flies are again crossed, the following generations are partly red-eyed – without further temperature treatment – even though only white-eyed flies are expected according to the rules of Mendelian genetics <http://www.sciencedaily.com/releases/2009/04/090412081315.htm>
39 Ceausescu also clamped down on anything psychological and in social work, preferring engineering and science.
40 Or worse, some reports suggest physical and sexual abuse of the children. One can read a lot about these orphanages by googling Romanian orphanages. The neglect first came to light in 1989.
41 Dr. Jean Clinton, personal communication
42 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 3: Development of the Human Brain
43 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 3: Development of the Human Brain
44 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 3: Development of the Human Brain
45 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 3: Development of the Human Brain
46 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 8: Infancy – Temperament and Attachment
47 Dr. Stephen P. Hinshaw Ph.D., Origins of the Human Mind, (Faculty of Psychology, University of California, Berkley, 2012) at Lecture 6: Instinct, Learning and Emotion
48 Dr. Steve Suomi, “Epigenetic consequences of early adverse childhood experiences in primates” (delivered at the Sackler Colloquia), December 2011
49 Dr. Steve Suomi, “Epigenetic consequences of early adverse childhood experiences in primates” (delivered at the Sackler Colloquia), December 2011
51 John Cloud, “Why Your DNA Is Your Destiny”, Time Magazine (January 6, 2010), reporting the work of Joseph R. Ecker, PhD, Professor, Plant Molecular and Cellular Biology Laboratory, and the Salk International Council Chair in Genetics, cited by Time Magazine for having one of the most important scientific findings in 2009; also reporting the work of Dr. Lars Olov Bygren, Karolinska Institute in Stockholm,
“Epigenetics: DNA Isn’t Everything”, ScienceDaily (Apr. 12, 2009); see also “Epigenetics: 100 Reasons to Change the Way We Think About Genetics”, ScienceDaily (May 20, 2009)

One mechanism appears to be methylation in which small chemical groups called methyls, attach to the DNA strand turning off the particular gene. The result of the turning on or off of a particular gene is passed from generation to generation and can have a long term effect across generations; Francis Champagne, “Session IV Gene-Environment Interplay in Socially Partitioned Health, Development and Behavior”, (delivered at the Sackler Colloquia, December 2011)

Francis Champagne, “Session IV Gene-Environment Interplay in Socially Partitioned Health, Development and Behavior”, (delivered at the Sackler Colloquia, December 2011)

“A Father's Stress May Affect His Unborn Children”, ScienceDaily (August 31, 2011)

The underlying data for this study was from Western Australia's long-term cohort Raine Study of 3000 pregnant women: “Repeated Stress in Pregnancy Linked to Children's Behavior”, ScienceDaily (April 20, 2011)


Wikipedia definition: In the human body, the most abundant catecholamines are epinephrine (adrenaline), norepinephrine (noradrenaline) and dopamine. Release of the hormones epinephrine and norepinephrine from is part of the fight-or-flight response: Wikipedia, online: <http://en.wikipedia.org/wiki/Catecholamine>

For the rats, the complex environment was the housing.

The period just before and just after birth.


Definition from Wikipedia


For an excellent book on this whole subject: Norman Doidge, The Brain That Changes Itself, Stories of Personal Triumph from the Frontiers of Brain Science (New York: Viking, 2007) also published by the
Penguin Group (USA). You can also get the book as an e-book. I rely on this book for all of my comments on neuroplasticity.

72 The Brain That Changes Itself