

The neurobiological effects of childhood maltreatment

An often overlooked narrative related to the long-term effects of early childhood trauma?

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Much discussion and research has been undertaken to explore ways of influencing the social determinants of health. Most highlight the need for change in socio-economic status or its environmental correlates (e.g., poor housing) to ameliorate negative social impacts.

Brain injury in children as a result of maltreatment, from the subtle to the glaringly obvious, has been well documented from early in-utero, and may continue to affect development well into the third decade of life.

This paper aims to discuss the concept that some current societal dysfunction may well be an overlooked significant consequence of childhood maltreatment, with its associated trauma effect upon the developing brain. These changes prevent and impair the ability to remediate disadvantage and its effects through purely social policy and justice measures.

We review current scientific knowledge of the effects of childhood maltreatment from a neurobiological perspective, a field of research that studies the relationship

between observed behaviours and evidence of co-existing structural and functional brain changes. Although the studies are primarily from overseas, the populations assessed are nonetheless similarly diverse in their makeup and may therefore provide insights that are equally relevant to our Australian population.

With growing concern about the extent of child maltreatment over the past 25 years in Australia, and the proliferation of a range of social policy responses to child maltreatment deriving from a plethora of judicial and other reviews (which have often been informed by different theoretical understandings of causation and responses), it is important to ensure that a neurobiological narrative forms part of the framework for understanding the impact of child abuse and formulating appropriate responses to it at an individual and societal level. Knowledge of the impact of maltreatment on the developing brain becomes essential for determining how to best advocate for the child, as well as provide protection and care.

Definition of childhood maltreatment

Historically, the definition of childhood trauma only included “acts of commission” to the child; that is, physical, sexual and emotional (psychological) meted-out acts of abuse. However, studies of children over the last decade (e.g., Beers & De Bellis, 2002; De Bellis, Hooper, Spratt, & Woolley, 2009; De Bellis, Keshavan, Shifflett et al., 2002; MacMillan et al., 2009; Price-Robertson & Bromfield, 2009) have increasingly demonstrated the need to also include in this definition “acts of omission”; that is, neglect in its various forms, including failure to comply with medical treatment such that significant harm results, and failing to protect a child or young person from witnessed violence (see Box 1).

Neglectful acts have also been extended to include the exposure of children to cigarette smoke when they are motor vehicle passengers, although this does not yet apply to the unborn foetus. Exposing foetuses to harmful agents (teratogens) could also be regarded as neglectful when there is a known causal relationship between the substance and resultant structural malformations to the developing foetus (e.g., continued thalidomide use despite knowledge of its effect on foetal limb growth, or continued alcohol use with knowledge of its causality in foetal alcohol spectrum disorder). Such actions are neglectful regardless of the intent of the child’s parent, caregiver or other responsible adults.

Neglect in most cases of antenatal substance abuse (including alcohol and tobacco) is often judged on the basis of its likely interference with the parents’ capacity to care for the child after birth rather than the likelihood of the chemical affecting the health and wellbeing of the foetus. For example, there is now a growing body of evidence demonstrating that ingestion of alcohol during pregnancy places a child at risk of developing foetal alcohol spectrum disorder, which has neurobiological effects on the foetus and young child (Guerri, Bazinet, & Riley 2009). These are likely further compounded, as similar areas of the brain are also affected when children are also exposed to family violence.

The common factors in trauma or maltreatment that adversely affect early brain development appear to be those events and conditions in which the child experiences or repeatedly experiences, in a prolonged and uncontrolled manner, circumstances that they perceive as being likely to be significantly life threatening for themselves (Chrousos & Gold, 1992; De

Box 1: Categories of maltreatment

Acts of commission (actions against the child)

- Physical—The child is subject to disciplinary action by his/her caregiver(s), with resultant bruising, severe pain, temporary loss of mobility, scars, burns, shaking etc. This may lead in some cases to more serious and life-threatening injuries, including inflicted brain injury.
- Sexual—This involves the sexual abuse or exploitation of the child and /or exposing them to sexual acts.
- Emotional—The child is subject to repeated verbal abuse, being sworn at or receiving hurtful and demeaning comments about his/herself. This form of maltreatment also includes the child hearing about violent acts perpetrated upon a significant attachment figure for the child.

Acts of omission (actions of failed care)

- Witnessing family violence—The child hears or watches aggressive verbal altercations and/or physical violence.
- Neglect—This type of maltreatment ranges from failing to provide basic food, shelter, clothing and care (including relevant medical care) to exposure to harmful substances. This is often labelled as “environmental circumstance”, but studies of documented behavioural features and neuro-imaging tests demonstrate that the resultant brain injury patterns are similar to those seen in children exposed to acknowledged trauma and maltreatment.

Sources: Chrousos & Gold (1992); De Bellis (2002); MacMillan et al. (2009)

Bellis, 2001; De Bellis, Hooper, Woolley, & Shenk, 2010; De Bellis, Keshavan, Shifflett et al., 2002)

Studies comparing these children with those for whom there is no evidence of them having been exposed to similar maltreatment demonstrate compelling differences in neuroanatomy and cognitive function that suggest that the impact of maltreatment has the potential to cause significant impairment of brain structure and function (De Bellis, Keshavan et al., 1999).

Neurobiological research studies

The earliest understanding of brain injury from substance exposure and maltreatment induced in children began with observations of changes in behaviour and cognitive function, matched with anecdotal recommendations on how to best care and “grow up” the child.

The earliest structural brain injury evidence began to be collated from around the early 1970s, when Drs Jones and Smith matched post-mortem autopsy analyses of brain changes with clinical histories of child maltreatment prior to death. However, with this method, only gross structural changes could be recognised (Guerri et al., 2009; Norman, Crocker, Mattson, & Riley, 2009).

Research into the neuropsychological development of humans began with

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observational studies in longitudinal and cross-sectional samples, in which observed behaviours were matched against known demographic, environmental, social and health factors (De Bellis, 2005; Giedd et al., 1999). Some of these included twin studies, which allowed adjustment for the possible influence of genetic factors, as well as gestational factor vulnerability (i.e., effects of events experienced during foetal growth) (De Bellis, 2001, 2002; De Bellis, Hooper et al., 2009). The documented behaviours were subsequently compared with the findings of neuropsychometric assessments (De Bellis, Hooper et al., 2009). These neuropsychometric tests included the Wechsler Pre-School and Primary Intelligence tests; measures of reading ability, caregiver intelligence, and the home environment; and the NEPSY neuropsychological assessment (face memory and narrative memory testing) (De Bellis, Hooper et al., 2010). Gender, socio-economic status and prenatal substance exposure were also taken into account.

Earlier work relying on the examination of brain structure through post-mortem study has now been largely superseded by in vivo assessments (of living children) through the use of non-invasive static-scan neuro-imaging tools, such as MRI (magnetic resonance imaging), DTI (diffusion tensor imaging) and SPECT (single-photon emission computed tomography). More recently, assessment with “functional MRI” (fMRI) has provided even further evidence of the impact that maltreatment has upon a child’s brain, including the assessment of not only structural changes but also the dynamic processes occurring within the brain as the child recalls or listens to an account of the varying types of maltreatment to which they have been previously exposed (Guerri et al., 2009).

Methods of assessing brain injury

Neuropsychometric assessment

Neuropsychometric assessments describe the correlation between observed behaviours and functional processing within the brain. To this end, they have provided evidence of the cognitive, learning and memory deficits noted in children who have attendant maltreatment histories. Within the specialty field of neuropsychology, assessment also permits the provision of experiential advice on how to best manage and remediate the functional deficits found (Goh et al., 2008).

Several tests (e.g., Wechsler Non-Verbal Scale of Ability, NEPSY, WISC: Wechsler Intelligence Scale for Children, etc.) are

commonly used to evaluate cognitive function (memory, concentration, and problem-solving ability and capacity). These tools assist in identifying specific functional problems affecting memory, attention and concentration; organisational, planning and multitasking skills; communication; spatial and visual skills and capacity; and writing and reading abilities; as well as disturbed thinking, confusion, impulsivity and behaviour inhibition problems.

The assessments are undertaken through a series of face-to-face interviews, history-taking and task-completion exercises that reflect the child’s ability to problem-solve, maintain attention and concentration, and recall memories. They also allow the assessment of language development and motor skills.

A limitation of these measurement tools, however, is that it is difficult to assess children under 5–6 years age due to their lack of developmental capacity to understand what is required of them. There are, however, other assessment tools, such as the Bayley Scale of Infant and Toddler Development, that are designed to overcome these difficulties, but require experienced psychologists to interpret the behaviours of the very young child.

Neuro-imaging

The advent of neuro-imaging of children with documented child maltreatment histories has provided irrefutable evidence of the structural and functional changes that occur within the brains of these children, corroborating observations about their behaviours and cognitive functioning (De Bellis, Keshavan, Frustaci et al., 2002; De Bellis, Keshavan, Shifflett et al., 2002; Kumar et al., 2009; Thomas & De Bellis, 2004).

Since the advent of more complex imaging tools from the 1990s onwards (see Box 2), scientific evidence on maltreatment-induced brain injury has rapidly accelerated, such that it now permits identification of more subtle injuries (Beers & De Bellis, 2002; MacMillan et al., 2009). Each of the studied areas within injured brains has demonstrated significant behavioural and cognitive developmental deficits in maltreated children, and the implications this has for the ecosystems within which the child develops and interacts (Beers & De Bellis, 2002; Bremner et al., 1999; De Bellis, 2005; De Bellis, Broussard et al., 2001).

Neuro-imaging techniques have permitted the evaluation and comparison of children known to have suffered maltreatment with those who have not, thus providing a stronger platform from which to advocate for the needs of the child.

Neurodevelopment of the brain

Evidence from neuropsychometric tests and neural imaging studies coupled with behavioural observation have provided much knowledge on the normal development of the human brain (Chrousos & Gold, 1992; De Bellis, Baum et al., 1999; Giedd et al., 1999).

The development of the human brain commences with an over-production of neurons in utero, followed by selective pruning (apoptosis) of nerve cells and the connections between them, especially in the grey matter (the region of the brain made up of nerve cell bodies) and their dendrite branch extensions (connections between cells). In the pre-adolescent years, grey matter increases rapidly and then, in the post-adolescent years, decreases as a result of pruning. Additionally, from 5 to 18 years of age, the process of oligodendrocyte myelination (encasing of the nerve fibres) increases, reflected in the thickening of the white matter (the region of the brain made up mainly of nerve fibres, with few nerve cell bodies and dendrite extensions) in the cortex. The ratio of cerebral grey matter to white matter decreases after 4 years age, further reflecting preferential pruning and a reduction in synaptic density in the grey matter as the brain develops (De Bellis, 2001).

Neurobiological trauma/ maltreatment: Stress response systems

The biological stress response is a normal adaptive system that activates physiological and behavioural change within the body to enable a survival response to mild, brief and controlled stressors. This activation of the stress response system enables emotional and intellectual growth and development (see Box 3).

Maltreatment that comprises severe, prolonged and uncontrolled life stressors activates a prolonged biological stress response. This response is mediated through the limbic-hypothalamic-pituitary-adrenal axis, a system that describes the brain's interaction with the peripheral body through neural (sympathetic nervous system) and hormonal (adrenal gland) tissues that regulate the body's response to perceived longer acting stressors (infection, trauma, neglect, substance exposure, etc.). (Chrousos & Gold, 1992).

The developing brain is particularly vulnerable to stress, especially with respect to the pre-frontal cortex, hippocampus and corpus callosum. Through prolonged activation of the

Box 2: Types of neuro-imaging

Magnetic resonance imaging (MRI)

In the 1970s, MRI studies initially confirmed post-mortem gross anatomical findings in injured brains. Later, MRI findings in living children with and without a history of child maltreatment were matched with neuropsychological assessments. MRI allows a non-invasive, safe brain examination to be made that provides a static image showing brain structure, physiology and function.

Diffusion tensor imaging (DTI)

DTI is a non-invasive, *in vivo* test that examines the microstructural differences in the brain by tracking the diffusion of water molecules and their displacement in brain tissue, so demonstrating changes in white matter (the conductive pathways), myelin (the supporting material around the connections between nerve cells), cell membranes, intracellular micro-tubules and axons (connection between nerve cells), as well as the corpus callosum. These areas provide a sensitive indicator of brain injury (Kumar et al., 2009).

Magnetic resonance spectrometry (MRS)

MRS assesses cellular metabolism through the measurement of metabolite and neurotransmitter levels and ratios, and cerebral blood flow analysis to reflect neural tissue function; that is, neuron (nerve cell) viability and axon integrity.

Single-photon emission computed tomography (SPECT)

SPECT facilitates the assessment of cerebral blood flow and biochemical processes of the brain.

Positron emission tomography (PET)

PET scans enable assessment of glucose metabolism (the primary energy source for neural tissue), and thereby neural integrity, through the use of injected radio-ligands taken up into the brain. This method of imaging is not recommended in children due to the use of radio-isotopic material. It is therefore used retrospectively in adults, in correlation with their childhood maltreatment histories.

Functional magnetic resonance imaging (fMRI)

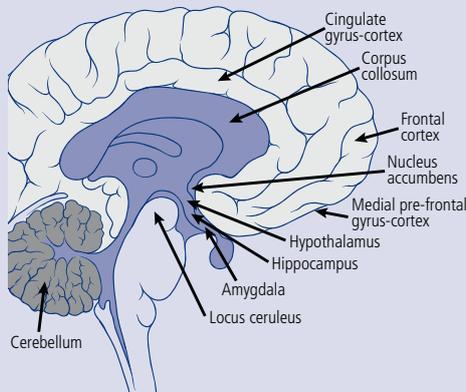
fMRI is used to assess the relationship between behavioural and biochemical findings in the brain tissue as a "real-time" relationship study. The difference between oxygenated and de-oxygenated haemoglobin across magnetic fields reflects neural activity through blood flow. Studies are carried out with the child actively listening or watching a triggering script related to their maltreatment experience and their brain responses are imaged in real time.

biological stress response system, structural and functional brain changes occur. The behaviours resulting from chronic stress include poor self-regulation, increased impulsive behaviours, and emotional responses such as high levels of experienced anxiety, aggression and suicidal tendencies and, in some, a learned helplessness from the constant impairment of self-regulation (De Bellis, 2001). Neuro-imaging in these cases provides evidence of accelerated loss and metabolism of neurons, with an abnormal pruning of axons, an inhibition of neuronogenesis (growth of brain cells) and

Box 3: Parts of the brain and development

Mid-brain

- The primitive part of the brain.
- Acts as a “relay station” for visual and auditory messages between itself and the brain stem, and generates neural responses to ensure immediate self-preservation through instinctual behaviour.



Limbic system (amygdala, hippocampus, hypothalamus)

- A set of evolutionarily primitive brain structures involved in emotion and motivation, particularly those related to survival, including fear, anger, pleasure, and emotions related to sexual behaviour.
- Involved in memory, determining what memories are stored and where they are stored in the brain, and so determining the magnitude of emotional response that an event invokes.
- Undergoes non-linear growth from childhood, peaking in adolescence at around 16 years of age.

Cortex

- Area of executive functioning: consequencing (i.e., the ability to understand the consequences of actions), sequencing and comprehension.
- Made up of two layers: (a) grey matter, which increases in a non-linear manner until around 16 years of age; and (b) white matter, which is involved in executive cognitive function in planned behaviour and working memory and continues to develop into the third decade of life.

Corpus callosum

- Only found in placental mammals.
- A bundle of commissural (connecting) nerve fibres within the brain that is especially vulnerable to injury through its anatomical location.
- Integral to the connecting processes between the left and right cerebral hemispheres, facilitating cortical communication with and integration between input from the mid-brain, cerebellum and cortex.
- Structurally provides interhemispheric transfer of auditory, visual, sensory and motor information, enabling cognition processes in the cortices.
- Non-linear development from 6 months to 3 years of age, with myelination by oligodendrocytes from around 5 to 18 years of age.
- Linear development continues into the third decade of life.

Cerebellum

- Main development occurs during the post-natal period.
- Involved in emotion, cognitive development and autonomic regulation through a biofeedback response.

Sources: Chrousos & Gold (1992); De Bellis (2001, 2005); De Bellis, Keshavan, Shifflett et al. (2002); Giedd et al. (1999); Kumar et al. (2009)

a decreased level of brain growth factors (Chrousos & Gold, 1992; De Bellis, 2005; De Bellis, Baum et al., 1999; De Bellis, Keshavan, Clark et al., 1999; De Bellis, Keshavan, Frustaci et al., 2002).

The biological stress response is regulated through two main systems—the hypothalamic–pituitary–adrenal system and the sympathetic nervous system—both of which are also involved in the regulation of the immune system (Chrousos & Gold, 1992; De Bellis, Baum et al., 1999; De Bellis, Keshavan, Clark et al., 1999). Neurotransmitters and hormones have been noted to be significantly involved in the activation and transmission of the biological stress response, and to mediate observed behaviours as well as changes within the brain structure by modulating the processes of neuronal migration, differentiation and synaptic proliferation, and thereby exert an effect across the whole brain. (Chrousos & Gold, 1992; De Bellis, 2001, 2005; De Bellis, Baum et al., 1999; De Bellis, Keshavan, Clark et al., 1999).

Several studies (e.g., De Bellis, Baum et al., 1999; De Bellis, Hooper et al., 2010; De Bellis, Keshavan, Shifflett et al., 2002; MacMillan et al., 2009) have hypothesised that the response to chronic stress impairs the function of noradrenaline and dopamine within the limbic system and that this may account for the typical post-traumatic stress disorder (PTSD) symptoms of persistent hyper-arousal and hyper-vigilance that continues to occur after the trauma, despite resolution of the initiating experience. These neurotransmitters also interact with the serotonin system to modify mood and anxiety symptoms.

In utero alcohol exposure: Foetal alcohol spectrum disorder

In many cases of child abuse and neglect, there is a co-occurrence of family violence with drug misuse, especially alcohol abuse, such that many of these children are at risk of being exposed to alcohol and other drugs in utero (Bromfield, Lamont, Parker, & Horsfall, 2010).

Data from the United States on the prevalence of foetal alcohol spectrum disorder suggests an affected population rate of approximately 1% of live births (Chasnoff, 2010). In Australia, birth prevalence estimates for foetal alcohol syndrome (the “full-blown” disorder, with marked facial abnormalities, brain impairment and growth deficiencies) range from 0.06 to 0.68 per 1,000 live births. However, for Indigenous children, the prevalence is estimated to be considerably higher, at 2.76 per

1,000 live births in Western Australia and 4.7 per 1,000 live births in the Northern Territory (Mutch, Peadon, Elliott, & Bower, 2009).

Babies with foetal alcohol syndrome have smaller head circumferences at birth and consistently lower IQ scores, as well as diminished executive functioning, short attention spans, difficulties in behavioural regulation, hyperactivity, impulsivity, clumsiness, poor balance, problems with writing or drawing, social deficits and poor judgement affecting management at school and at home. Not only is overall brain size reduced, but the growth of individual parts of the brain is also affected and these children frequently have difficulty thinking in the abstract and moving information from one region of the brain to another. MRI studies of children with foetal alcohol syndrome have shown thinning of the corpus callosum, which disrupts communication between the two halves of the brain (Guerra et al., 2009; Norman et al., 2009).

Alcohol has particular effects on the limbic system, including the hippocampus, where damage results in difficulty transferring information and memories to long-term memory storehouses in the temporal lobes. Furthermore, alcohol use during the third trimester of pregnancy causes damage to the cerebral cortex of the foetus, with reduction in the brain surface area as a result of interference with the development of the brain's gyri and sulci (the valleys and ridges on the surface of the brain)—a condition known as lissencephaly.

Thus, prenatal exposure to alcohol followed by maltreatment after birth constitutes a double blow.

Maltreatment outcomes

The impact of maltreatment on the brain—structural, functional and behavioural—has been shown to worsen the longer the duration of trauma experience and the younger the age of onset of the trauma experience (De Bellis & Kuchibhatla, 2006). These findings are specific to maltreatment-related PTSD and are significantly different from those of children with general anxiety disorders.

Substance misuse and dependence

Studies have also demonstrated that higher levels of substance misuse and dependence are associated with a decrease in hippocampal volume, though this is potentially reversible upon removal of the child from the traumatic stressor (De Bellis, Keshavan, Shifflett et al., 2002).

Alcohol and several of the commonly used illicit recreational substances have been noted to dampen the hyper-arousal PTSD symptoms, and hence have been postulated as being a self-medication measure in adolescents who have experienced maltreatment. This group of young people appear to be more susceptible to developing dependence and addiction as a result of the toxic effects of these substances, especially to the hippocampus (De Bellis, 2001, 2002; De Bellis, Hooper et al., 2009; De Bellis, Keshavan, Clark et al., 1999).

Mental health disorders

Early onset adult depressive, suicidal and personality disorders have also been shown to be significantly increased in those with documented histories of childhood maltreatment (De Bellis, 2001; De Bellis, Broussard et al., 2001; Thomas & De Bellis, 2004). This has been postulated to be the outcome of cortisol hyper-secretion.

Of interest is the finding that “antisocial” personality disorder is a more frequent occurrence in those with a history of physical abuse and/or neglect, whereas “borderline” personality disorder is more frequently associated with childhood sexual abuse (De Bellis, 2005; Johnson, Cohen, Brown, Smailes, & Bernstein, 1999; Walker et al., 1999)

Neglect

During normal development, parents provide their children with their fundamental needs in relation to attachment, play, learning, being protected, and physiologic and emotional regulation. A lack of experience of stimuli for the provision of these fundamental needs results in delayed myelination of axons, with resultant loss of executive function capacity and self-regulatory behaviours (De Bellis, 2005).

Violence and post-traumatic stress disorder

Cognitive development and academic performance are also adversely affected by childhood exposure to violence. MRI studies show that exposure to violence is associated with children having smaller intracranial, cerebral and prefrontal cortex volumes, with particular effects on prefrontal white matter, temporal lobe volumes and the corpus callosum. Also noted in these studies is an increase in the volume of prefrontal cerebrospinal fluid (the nutrient and buffering fluid around the brain and spinal cord), reflecting a loss of brain volume. Functionally, these children have been found to suffer increased

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levels of depression, dissociation and both externalising (aggression, self-harming) and internalising (depression, anxiety) symptoms (De Bellis, Broussard et al., 2001; De Bellis & Keshavan, 2003; De Bellis, Keshavan, Clark et al., 1999; Thomas & De Bellis, 2004).

Of particular interest is that MRI studies demonstrate that male children are more vulnerable to the consequences of maltreatment, and this is reflected in changed brain structure (De Bellis, 2001; De Bellis & Keshavan, 2003). The corpus callosum volume in males is especially decreased in the isthmus region of the corpus callosum, which appears to facilitate more externalising behavioural symptoms of aggression and suicidality.

A similar decrease in volume is noted in the superior temporal gyrus and hippocampus, with a resultant observed deficit in executive function ability and sustained attention and focus, a limited verbal response ability, and poor short-term memory and capacity for future planning. Also observed has been a decreased ability to learn through both motor and non-motor means. Further, the cerebellum is generally decreased in volume in these children, with an observed attendant behavioural pattern of having difficulty sleeping, poor concentration and general irritability (De Bellis, Keshavan, Shifflett et al., 2002)

Sexual abuse and exposure to domestic violence

Child sexual abuse and witnessed domestic violence have been noted to be the commonest causes of PTSD and induced brain change. The structural brain changes (especially of a decreased cerebellar volume), as evidenced on anatomical MRI, correlate with the presence of PTSD symptoms. Children and adolescents with generalised anxiety disorder but no attendant maltreatment histories do not demonstrate the brain changes that have been documented in cases of childhood maltreatment (De Bellis & Kuchibhatla, 2006)

Poor physical health

Maltreatment in early childhood has also been shown to result in adverse adult onset physical health; in particular, chronic disease and reproductive and adult sexual health problems (Quas et al., 2005). It is hypothesised that the biological mechanism may be mediated through the immune system as a result of dysregulation arising from prolonged activation of the limbic-hypothalamic-pituitary-adrenal axis and sympathetic nervous system (Chrousos & Gold, 1992; De Bellis,

2005). One of the most influential studies contributing to our understanding in this area has been the Adverse Childhood Experiences Study, involving over 17,000 adults in San Diego, undertaken in a partnership between the Kaiser Permanente Health Maintenance Organisation and the Centers for Disease Control and Prevention in Atlanta (Anda et al., 2005). These authors concluded that childhood abuse and exposure to domestic violence can lead to numerous differences in the structure and physiology of the brain, which affect multiple human functions and behaviours.

Resilience

Neuroplasticity

Although there is increasing evidence of brain injury being associated with child maltreatment, and its consequent behavioural impact, not all children are adversely affected in this way. Some of this resilience may be attributed to the "neuroplasticity" of the brain; that is, the ability of neural tissue to modify brain function and response, so enabling a different response to an experienced memory. Neuroplasticity occurs as a result of some synaptic pathways being enhanced rather than others following activities that stimulate specific sensory, motor and language development. This is especially seen in children under the age of 7 years and continues to a lesser degree into the mid-teenage years, but it decreases significantly around the third decade of life, when the brain has reached maturity with completed myelination (Mundkur, 2005).

This neural tissue resilience suggests that appropriate and early remedial therapy provided to children who have suffered maltreatment (either in utero, or during their childhood), may mitigate many of the adverse behavioural, learning and cognitive effects of the maltreatment (De Bellis, Keshavan, Shifflett et al., 2002).

Epigenetics

Environmental events can directly modify the epigenetic (hereditary expression) state of the genome (inherited information encoded in DNA). Rat studies have demonstrated that environmental signals can activate intracellular pathways to directly remodel the epigenome, leading to changes in the way genes are expressed, and with subsequent changes in neural function. Zhang and Meaney (2010) concluded from their studies that there is "a biological basis for the interplay between environmental signals and the genome in the regulation of individual differences in





behavior, cognition and physiology” (p. 439). Furthermore, these authors found that variations in mother–infant interactions that lie within the normal range for a species can directly influence gene expression and behaviour; that is, the offspring of rats experiencing a high level of tactile stimulation, which regulates their endocrine and cardiovascular function, show more modest behavioural and endocrine responses to stress (less fear and reduced hypothalamic–pituitary–adrenal activity) than the offspring experiencing less maternal interaction. This occurred even when repeated in foster parent studies. Zhang and Meaney therefore concluded that “these findings provide a potential mechanism for the influence of parental care on vulnerability/resistance to stress-induced illness over the lifespan” (p. 446).

It is thought that similar epigenetic modifications also occur in humans in response to variations in parent–offspring interactions (Zhang & Meaney, 2010).

Discussion

The well-demonstrated impact of child maltreatment on the developing brain—both antenatally and post-natally—as well as the resultant psychobiological (physical, cognitive, emotional and behavioural) consequences may be better described as an “environmentally-induced developmental disorder” (Chrousos & Gold, 1992; De Bellis, 2001, 2002).

Early identification of such affected children would permit the implementation of remedial social supports, education and behavioural treatment measures to enhance the modifying mechanism of neuroplasticity to reduce the functional neurobiological effects of child maltreatment. Additionally, early modification of the child’s environment to decrease the biological stress response may also assist the expression of the child’s genetic make-up (epigenetics).

Individual perspective

The level of impact of maltreatment on a child’s biological stress system is reflected in the child’s subsequent cognitive and behavioural development, the extent of which is dependent upon the age of first exposure and the duration of the maltreatment suffered.

Elevated cortisol biological stress responses in children and adolescents reflect the prolonged stimulation of the hypothalamic–pituitary–adrenal axis, which normally is an acute stress response system. This prolonged stimulation in turn adversely affects physical and mental health

and wellbeing, resulting in conditions such as reduced immune function, cardiovascular disease, dysthymia (persistent mild depression), major depression, oppositional defiant disorder and attention deficit hyperactivity disorder (ADHD). Furthermore, persistent exposure to stress results in damped responsiveness to new stressors (MacMillan et al., 2009).

As noted previously, many of these children and adolescents are also more susceptible to developing alcohol and illicit substance dependence, which in some cases is a form of self-medication aimed at dampening down the hyper-arousal symptoms of their dysregulated biological stress responses (De Bellis, 2001).

The apparent gender differences in the responses to maltreatment have also been noted, as females tend to express their responses to maltreatment through internalising symptoms such as depression, anxiety and eating disorders, compared to males, who express themselves more through externalising symptoms such as aggression, harm directed at others and suicidality (De Bellis, 2001; De Bellis & Keshavan, 2003; De Bellis, Keshavan, Clark et al., 1999).

The differential expression of emotional response appears to be age-dependant, as younger children appear not to be as differentiating in expression of their emotional distress. In other words, the younger child tends to display a similar level of distress regardless of the magnitude of stress to which they are responding (Dade-Smith, 2007).

As a result of the immediate effects of maltreatment (whether induced antenatally by drugs, including alcohol, or post-natally by abuse) and ongoing heightened biological stress response and their subsequent neurobiological changes, the child’s learning capacity and executive cognitive functioning is impaired, with a resultant inability to achieve the academic functioning and skills needed to underpin adult function.

Family perspective

The impact of child maltreatment within the family unit is dependent upon the functioning of that unit as well as the availability and accessibility of other supports. Chronic alcohol abuse is also likely to impede family functioning. Supports that assist the child regulate his or her emotions following a maltreatment event significantly affect the duration of the biological stress response in the child, as well as limiting the adverse impact of the child’s behaviour upon the family unit. Poor family coping capacity is likely to influence

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adversely the parent–child relationship and the parents' ability to support the child through the biological stress event, with an increased likelihood of subsequent child mental health issues (Dade-Smith, 2007).

Poor individual functional capacity due to mental health issues and/or learning and executive functioning difficulties further limits the ability of the child to achieve adult-independent function, placing a further burden upon the families of maltreatment-affected children.

Importantly, not all children are adversely affected by maltreatment, and this is hypothesised to reflect their access to appropriate environmental and familial supports at the time of the event. Additionally, differential epigenetic responses to environmental circumstances may also play a part. If the biological stress response is rapidly curtailed through appropriate support, and safety and security measures are instigated, then structural changes within the developing child's brain are likely to be minimised, along with the adverse behavioural consequences (De Bellis, 2001; Goh et al., 2008).

Community perspective

Reports on the social determinants of health emphasise that overarching poverty affects all aspects of a community's health, including the likelihood of its children being maltreated (Nisbet & Seidler, 2001). The effects of maltreatment on children extend further than the children and their respective families to affect the wider community. The learning and cognitive deficits observed in these children are then reflected in their poorer educational and life skills development, particularly their capacity for self-regulation. This in turn affects the community's ability to control violence and ensure an environment that promotes individual safety.

Children from impoverished communities where levels of interpersonal and community violence and neglect are high, experience significantly increased rates of foster care, delinquency, adolescent sex offences, youth justice encounters, homelessness, unemployment, and adolescent substance misuse and dependence (Al-Yaman & Higgins, 2011; Dade-Smith, 2007).

Child maltreatment eventually also affects the broader society with which the child's community articulates. When adults in these communities have also been affected in their own childhoods by significant and chronic maltreatment, and witnessed or experienced personal, family and community violence, as

well as engaging in chronic alcohol misuse, the intergenerational "cycle of poverty and community dysfunction" continues; the adults who would normally be responsible for providing the leadership, supervision and caring roles are themselves limited by their own reduced cognitive capacity and executive function ability.

Possible assessment methods for Australia

Although we may not currently have ready access to the neuro-imaging tools of functional MRI, DTI, and SPECT scanning, evidence from studies undertaken overseas and the authors' own observations while providing community health care in remote, regional and urban Australia would suggest that there are other tools that could be developed, modified and used to permit early assessment and identification of the "at-risk" child with a history of maltreatment.

Identification of these children through early and appropriate screening (see Table 1) and targeted remedial treatment has the potential to mitigate some of the cognitive, learning and behavioural difficulties that may arise, such as poor literacy, unemployment, incarceration, childhood pregnancy, or substance dependence (Mundkur, 2005).

Conclusion

Childhood maltreatment can have far-reaching and lifelong neurobiological impacts that extend beyond the individual child and family. Where brain injury results from maltreatment, current social and justice strategies, often introduced relatively late in the individual's life, are by themselves of little benefit in achieving remediation, as the damage to neuropsychological functioning may be too entrenched to be overcome. This is especially so as most of the remedial programs available commence after the age of 7 years, thus missing the most sensitive "neuroplastic developmental" period.

Criminal justice responses to negative community behaviours may be better addressed through earlier awareness of the roots of these behaviours in neurobiological disorder and early remedial care of the underlying impairments that many maltreated children suffer (Goh et al., 2008).

Although Australia may not currently have the research and technological capacity to further study these children, we can extrapolate from the evidence of larger overseas populations to commence targeted neuropsychometric



Table 1 Childhood maltreatment assessment tools available in Australia

Assessment tool	Undertaken by
Early childhood assessment	Parents, early childhood health workers, general practitioners, paediatricians
School behavioural assessments	Teachers, social workers, general practitioners, paediatricians
Neuropsychometric tests	Clinical psychologists
Urinary catecholamine measurements (dopamine and noradrenaline 24-hr collections, diurnal salivary cortisol measures)	Paediatricians
MRI	Currently not easily accessible beyond major centres in Australia
Functional MRI	Currently not available in Australia

assessments and appropriate screening (see Table 1) to identify those children who, as a result of maltreatment, are at risk of learning, cognitive and behavioural difficulties, and implement appropriate and timely remedial supports. These include giving special attention to the needs of those children who have sustained severe maltreatment and are placed with non-biological carers. It is pleasing to note the increased recognition being given to the importance of assessing the health and educational needs of children in care, many of whom have manifestations of disturbed brain function of the kind we have described (Department of Families, Housing, Community Services and Indigenous Affairs, 2010). Additionally, it is often helpful for carers to have some understanding of the way in which their child's brain function is likely to have been affected by their early experiences (especially severe stress, trauma and insecure attachment), which in turn drives their difficult behaviour.

Recent work in the UK provides a model worthy of consideration. Given the variable experience of the benefits of the Sure Start program (Belsky, Barnes, & Melhuish, 2007) and early trials of sustained nurse home-visiting using the Family Nurse Partnership model, two recent independent reports to the UK Government have called for a substantial investment from the public and private sectors in evidence-based early intervention strategies across the age range 0–18 years, with special attention to those aged under 3 years (Allen, 2011a, 2011b). Many of these programs are consistent with what we know affects healthy brain development or remediates trajectories that have been adversely affected by maltreatment.

Evidence from overseas research and population studies clearly demonstrates the occurrence and patterns of longlasting structural and functional changes occurring in the brains of maltreated children with associated behavioural, learning and executive cognitive deficits. These functional impairments in the individual have

significant long-term consequences for society, with respect to both the high costs of secondary disability care for the affected individuals and increased costs incurred through the provision of additional law enforcement strategies to promote a safe and non-violent family and community environment. Providing a safe environment for children and their families will enable the next generation of children to achieve their maximum adult potential through normal neurobiological development.

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