

The significance of human–animal relationships as modulators of trauma effects in children: a developmental neurobiological perspective

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Emotional stress and trauma impacts the neurobiology of children. They are especially vulnerable given the developmental plasticity of the brain. The neural synaptic circular processes between the anterior cingulate cortex, prefrontal cortex, amygdala and the hypothalamus are altered. Trauma results in the release of the peptide glucocorticoid, or cortisol leading to an ongoing over-arousal of the anatomic nervous system. Kindling (sensitivity) of the brain, a result of stress, ironically makes the brain more receptive to attunement and enriched environments. Attunement with others as well as enriched environments is prophylactic, contributing to resilience and normal brain development. Animals are often attachment objects for children. Touch, proximity and mind–body interaction with animals have been found to contribute to stress reduction and trauma recovery. Future interdisciplinary exploration of the use of equine–human relationships as a preferred way of treating traumatised children should consider neural responses.

Keywords: equine–human interaction; neural resonance; traumatised children; attunement; human–animal relationships; developmental neurobiology

Introduction¹

It is estimated that 70 million households in North America have a pet. Animals are often constant companions for the elderly, children and the disabled. For children especially, young animals offer an opportunity to forge a relationship that is interactive, comforting and particularly non-verbal; in some ways not unlike the relationship human adults have with their infants and young children. Human–animal relationships appear to be rewarding on a number of levels. Trust, safety and structured interaction are important in animal companionship. Animal research confirms that all of these same ingredients are essential to normal and healthy development among all mammals (Yehuda & LeDoux, 2007; Panksepp, 1998).

Do animals contribute to an enriched environment for children? Can attachment and neural resonance in animal companionship impact on the brain in predictable and useful ways? Can these relationships be contributors to personality development, emotional and cognitive self-regulation and organisation? This critical review will explore human–animal relationships as possible contributors to neuro-developmental processes in children. It will discuss the role of these relationships in self-regulation

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and organisation, mediating the release of particular neuro-chemicals through attachment and interaction. It will discuss neural resonance as well as attachment. It will speculate on how these relationships might contribute to resilience, stress reduction and healing from the experience of trauma. Neuro-developmental processes related to the experience of neglect, abuse, maltreatment or trauma in children will be used as examples. Some reference to the use of animals as ‘mind–body techniques’ will be included.

Definition of terms

The concepts used in this article relating to human–animal interaction and developmental neurobiology warrant defining given the context of the discussion. The term animal refers to non-human animals typically domesticated and kept as companions. This can include mammals (cats, dogs, rabbits, rodents, horses or other livestock), or birds. Infants are newborns to two years of age and the term ‘children’ refers to those who are two years of age up to adolescence. Emotion refers to ‘bodily responses’ or ‘mental states’ that occur as a consequence of bodily responses (LeDoux, 1996, p. 23). Neuro-developmental processes refer to the growth of the human brain (physiologically) and mind (psychologically, emotionally and cognitively), in this case as it relates particularly to children from birth through to adolescence (Schore, 2003). Kindling is a process of sensitisation in the brain whereby a stressful event sensitises the brain to future experiences of stress through the development of neural pathways that fast track the response (Kramer, 1993).

Animal research and its relevance to humans

Theoretical determination of developmental neurobiology in humans relies on decades of research with animals, specifically other mammals. Animal to animal relationships provide a model that has facilitated the understanding of how ‘interactive attunement mechanisms’ (Stern in Schore, 2003, p. 4) between mothers and infants contribute to synaptic growth in the infant brain. Work with rats, mice and monkeys appears to demonstrate that the infant–caregiver relationship defines the early development of neural pathways enhancing or damaging both cognition and function into adulthood (Francis & Meaney, 1999; Glaser, 2000; Kramer, 1993; Panksepp, 1998). Meaney’s work is particularly compelling, demonstrating that early experience of stressors has long-term implications for hippocampal synaptic development and function (Liu et al., 1997). As well this research indicates that within a given window of developmental opportunity in the brain, access to a more responsive caregiver for rat pups, or the context of an enriched environment, can change neural processes after the fact. Rat pups that are gently handled by humans for short durations appear to be resilient in the face of further stress. In contrast, rat pups that are separated from their mothers for longer periods appear to experience kindling, have increased startle responses and a greater fear of novelty (Caldji, Diorio, & Meaney, 2000; Kramer, 1993). Over all maternal care affects hippocampal glucocorticoid receptors and hypothalamic-pituitary-adrenal (HPA) responses to stress, and adversity in early life enhances sensitivity to later forms of enrichment (Bredy, Humpartzoomian, Cain, & Meaney, 2003). Although this research does not necessarily indicate that developmental processes are homologous across species of mammals, the use of technology such as positron emission tomography (PET) scans

and functional magnetic resonance imaging (fMRI) has allowed contemporary neurobiologists to view the complex interaction in the animal and human brain in more detail. Research provides evidence that many of the processes are similar, albeit that human cortical activity is more complex and many aspects of development are still unknown (Panksepp, 1998). Johnson (2000) notes, 'the general neuroanatomy of the neocortex is remarkably similar across both regions (of the cortex) and species' (p. 76). These concepts are integral to a discussion of the impact of attachment in human–animal relationships on child brain development. The role of attachment in human–animal interaction is facilitated by a more in-depth discussion of developmental neurobiology and the role of the environment.

Neurobiology of emotion

Environment directly contributes to neurodevelopment and caregivers are an important aspect. Research in developmental biological processes in the brain supports the notion that infants and caregivers are highly tuned to each other neurologically. The process of touch (Francis & Meaney, 1999) and the use of 'motherese' (Schore, 2003) by the caregiver contribute to infant development through stimulation of the sub-cortical region of the brain 'involved in processing socio-emotional information' (p. 146). Specifically this would be the orbital frontal cortex (OFC) on the ventral surface of the prefrontal cortex (PFC) (Lewis, 2005b; Rolls, 1999). Research indicates that early experience plays a crucial role in social and emotional development specifically (Elbert, Heim, & Rockstroh, 2001). Enriched environments can contribute to resilience (prophylactic ability) or impact kindling (the amygdala's synaptic system is sensitive to stress) (Caldji et al., 2000; Curtis & Cicchetti, 2003; Kramer, 1993; Putnam, 2005). This complex process promotes stability in the development of the brain.

Chemical messages from limbic and brainstem centres described in the interaction between infants and primary caregivers are mediated by the response from the cerebral cortex. The infant's right ventral hemisphere interfaces with and is open to the caregiver's nurturing response, engaging the sub-cortical and limbic areas of the brain, specifically the amygdala, hippocampus and ventral anterior cingulate cortex (ACC). This relationship invokes emotion and emotion as a process, plays a key role in cognition (Lewis, 1995, 2005a, 2005b; Nelson, 2000; Schore, 2003; Todd & Lewis, in press). This cortical limbic interface is responsible for appraisal, perceptions, emotions, memory and other processes that drive biological regulation in the rest of the brain and body. Lewis (1995) describes how emotion is the context for self-organisation and ontogenesis or self-regulation of the brain, summoning peptides and triggering environmental attunement as part of synaptic development. The brain stem, along with the hypothalamus, releases opioids, oxytocin, vasopressin, dopamine, serotonin and other neuromodulators. This stimulates higher cortical systems like the ACC and OFC that respond by regulating, modulating and organising responses accordingly. Brain development is a matrix of these epicentres that dictate specialised change through experience-expectant (anticipated environmental processes) and experience-dependent (environmentally triggered) processes. Tucker refers to this process of simultaneous top-down and bottom-up reciprocal interaction as 'vertical integration' (Todd & Lewis, in press). Underdeveloped systems (very young infants) rely on sub-cortical/limbic responses and experience-expectant processes until cortical development can support the process of modulation on its own (Greenough & Black, 1992).

Self-regulation perpetuates coordination through the development of epicentres such as the ACC and OFC described as above (Todd & Lewis, in press). Highly activated systems recruit other systems, self-regulating the brain. Lewis (2005b) contends that these epicentres in the brain and the feedback systems between them contribute to rapid change, regulating towards stability. So it follows that experience provokes processes that result in emotion, which facilitates cognition and collectively with genetic predisposition, these processes simultaneously and reciprocally drive brain development, moment by moment, 'laying down structure' (Lewis, 2005b). These structural pathways develop through an integration of both open and closed systems in the brain, and they work to maintain the balance and order required to function, resulting in self-organisation. Lewis (2005b) notes that 'limbic and higher structures (cerebral cortex) may be considered "open" in that they change with development on the basis of experience, whereas lower structures are considered "closed" because they change little or not at all (Panksepp, 1998)' (p. 258). The process of self-organisation involves the development of a 'dynamic system' that relies on neural pathways, forged by experiences and pruned if underutilised, that are unique to the individual (Howe & Lewis, 2005; Johnson, 1998; Lewis, 2005a; Nelson, 2000). Self-organisation and regulation are impacted by attachment between the developing infant or child, the primary caregiver(s) and the environment.

Neurobiology of attachment

Glaser (2000) describes attachment as '...proximity-seeking behavior by a dependent organism (infant or child) when he or she experiences discomfort of any sort... it is a biological instinct (Bowlby, 1969)' (p. 102). Attachment networks in the brain dictate how these behaviours are organised, and are a consequence of nurturing or lack thereof, by an attachment figure (Schoré, 2003). They are facilitated by the release of neuropeptides such as oxytocin, endorphins (opioids) and prolactin from the hypothalamus (Panksepp, 1998). Bonding chemistries appear to be similar across species, within varying windows of time, ascribed to forge an attachment. Secure attachment can provide children with a buffer that modulates the effect of adrenocorticotrophic hormone (ACTH) on the HPA axis when stress is experienced (Glaser, 2000). Panksepp (1998) indicates that neuropeptides may create a feeling of security in children and ultimately contribute to '... these subtle feelings we humans call acceptance, nurturance and love – the feelings of social solidarity and warmth' (p. 248).

Attachment is different from neural resonance. Schoré (2003) likens resonance in infant caregiver relationships to affective attunement, a kind of emotional current that quickly spreads from one to the other. Schoré's notion of 'sympathetic vibration' (p. 76) contends that the laws of physics demonstrate attunement in relationships and lead to resonance between emotional states, resulting in feedback loops that connect the two individuals. Neural resonance can occur between individuals who have an affiliation or within the context of an attachment. There is little physiological evidence for this but some promising work has emerged looking at mirror neurons.

Recent research in the mirror neuron system in primates and humans would suggest that the firing of neurons in children may occur while observing the attachment figure the same way that they would fire when the child is performing the action, or a complementary action, themselves. '[M]irror neurons are not simply concerned with mirroring others, but they rather facilitate social interactions in which individuals

often perform complementary actions to achieve a common goal' (Iacoboni & Mazziota, 2007, p. 214).

Turella, Pierno, Tubaldi, and Casteillo (in press) caution that research to date on mirror neurons in humans is sparse with little support for a neural map of responsiveness in humans like the one discovered in monkeys (Di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992). Much of the research in human mirror neuron systems, they reviewed to date, has not sufficiently replicated the original primate research; however, in humans 'reasonable propositions have suggested that they (mirror neurons) mediate action observation and understanding' (Turella et al., in press). Research measuring mirror neural responses in autistic children concluded that responses only registered in EEG testing when the stimuli (observed actor) presented were familiar and socially relevant (Oberman, Ramachandran, & Pineda, in press). Stimuli in this case would be a person who is familiar. Other mirror neuron studies that have not produced support for this phenomenon in humans have studied the interaction using strangers instead of familiar individuals. The process of neural mirroring is different from the process of attachment but it could play a role in the complex neurobiology of attunement and affiliative behaviour.

The literature indicates that attachment requires a complex interactive process that relies on the development of schemas organised by the OFC (Schore, 2003). The primary caregiver and infant may share 'reciprocal activation of their opiate systems' (Schore, 2003, p. 81) which influences the development of the child's parasympathetic nervous system. Levitt (2005) calls this co-action, versus interaction.

Mirror neuron system sites appear to be most activated when humans imitate the facial expressions of others, suggesting that this may allow for empathy with another person's emotions (Iacoboni & Mazziota, 2007; Kaplan & Iacoboni, 2006). The body of research on mirror neurons, neural resonance and the contribution they make to attachment is sparse and new. Looking collectively at the developmental neurobiological literature it is important to understand the relevance it has to the social context that surrounds the child as they grow. Carter (1998) found that the neuropeptides, oxytocin and vasopressin were implicated in social bonding, lowering HPA activity, '... perhaps accounting for the health benefits that are attributed to loving relationships' (p. 779). This process also relies on the social networks that are formed around an infant. Infants and caregivers do not interact in a vacuum.

The Convoy Model of social networking describes the collective of individuals that surround an infant-caregiver relationship, creating a protective shell that contextualises life experiences (Antonucci & Akiyama, 1994). Social networks can serve to protect or create vulnerability and can augment or limit development. These networks are unique to each individual enhancing their feelings of competency, self-worth and self-efficacy. Social networks can buffer individuals from adversity and contribute to resilience, and attachment could very well play a part in that. Understanding the relationship between attachment networks, social networks and brain development helps to reinforce the importance of social interaction, love and connectedness to healthy neural development.

Animals are part of children's social network/enriched environment and long-term animal companionship may facilitate development by virtue of the proximity of the animal and the child's developmental plasticity. An introduction to the research into human-animal relationships is useful to understand the role they could play in buffering trauma as well as the contribution they might make to enriched environments.

Human–animal relationships

Research with companion animals is attempting to demonstrate that these relationships share some aspects of traditional attachment theory in human-to-human relationships (Crawford, Worsham, & Swinehart, 2006; Prato-Previde, Custance, Spiezio, & Sabatini, 2003). Clinical research indicates that animals respond similarly to children when exposed to Ainsworth's Strange Situation Test (Ainsworth, 1970). Animals mobilise the attention of children, calm agitated behavior and ameliorate emotional crises (Hart, 2000; Katcher & Wilkins, 1997; Strand, 2004). Kaiser, Spence, Lavergne, and Vanden Bosch (2006), using a pre-post design with a number of reliable and standardised clinical tests, found that a week of riding horses for young boys reduced anger. Reichert (1998) notes, in her work with childhood sexual abuse, 'a child often finds it easier to express herself through physical interaction with the animal rather than verbal communication' (p. 180). The psycho-physiological evidence indicates that companion animals impact humans in helpful ways, lowering blood pressure, quieting the autonomic nervous system, cardiovascular activity and promoting physiological relaxation (Friedmann, Katcher, Thomas, Lynch, & Messent, 1983; Odendaal, 1999, 2000; Shiloh, Sorek, & Terkel, 2003; Virues-Ortega & Bruela-Casal, 2006; Wilson, 1991).

Recent research that has measured cortisol levels and plasma levels of neuropeptides and neuromodulators, specifically endorphins, oxytocin, prolactin, phenylethylamine and dopamine in dogs and humans interacting suggests that human–animal relationships can mitigate stress responses (Odendaal, 1999, 2000; Odendaal & Meintjes, 2003). Affiliation in highly social beings like humans and other mammals demonstrates neuron-physiological responses that '... are in accordance with social bonding neuro-chemical changes' (Odendaal, 2000, p. 279). Human–animal relationships appear to have some impact on neuro-chemical processes in the brain, through attachment and affiliation. Do they have the capacity to contribute to resilience in the face of stress? A discussion of the impact of stress and the speculative role of human–animal relationships for children in the face of stress is warranted.

Animals as affective strategies with traumatised children

There are a number of events that can mitigate the healthy process of development in children, interfering with self-regulatory processes. Stress is particularly offensive to developing brain systems, causing long-term changes to the HPA circuit, in a number of ways (Bredy et al., 2003; Glaser, 2000; Kramer, 1993; Lewis, 2005b; Nelson, 2000; Putnam, 2005). Research has revealed the critical nature of the mind-body link in childhood development and how trauma interrupts it (Curtis & Cicchetti, 2003; Perry, 2006; Van der Kolk, 2003). Trauma is a result of extreme and chronic experiences of stress that can be both active (abuse) and passive (neglect). In children, stress impacts on neural developmental windows of opportunity, impairing the brain's ability to self-regulate and self-organise effectively. The developmental neurobiological research indicates that this results in sensitivity in the HPA axis, to subsequent experiences of stress, affecting neuron-chemical processes and ultimately impacting the development of epicentres in the brain (Kramer, 1993; Lewis, 2005b; Nelson, 2000; Putnam, 2005). The role of the OFC in all of this is pivotal – it is on alert (hypervigilant) focusing the individual's attention on the potential for harm. This results in a 'consolidation of habits' or 'emotional interpretation' identified by Lewis and Todd (2007) that creates a propensity for anxiety.

Exposure to trauma at various stages in childhood can skew, inhibit or alter processes of development that have a lifetime of consequences. Perry (2002) notes, '... the longer the child was in the adverse environment – the earlier and more pervasive the neglect – the more indelible and pervasive the deficits' (p. 92). He states that recovery is possible and echoes the sentiments of Van der Kolk (2003) regarding the use of touch, nurturing and social interaction as useful intervention techniques. Attachment plays an important role in this regard. Helping children reach a 'physiologic state' in which they can consider new possibilities is important – soothing, holding rocking, creating safety are examples of behaviours that move children to this place (Perry, 2002, 2006; Van der Kolk, 2003).

The use of animals with children is becoming increasingly popular in this regard. The extent to which neurobiological development is enhanced by a supportive and enriched environment, and what windows of vulnerability afford an opportunity for intervention is becoming clearer (Lewis & Todd, 2007; Putnam, 2005; Van der Kolk, 2003). Enriched and challenging environments impact aspects of development in infants and young animals as well; exposure to stimulating contexts appears to be prophylactic (Johnson, 2000; Nelson, 2000). Children might naturally seek affiliative relationships that are rewarding in this way. Phillips (2003) talks about the role of oxytocin and vasopressin in the brain systems focused on liking, and dopamine in the brain system focused on wanting, and their inevitable connection to pleasure. Seeking behaviour would be indicative of the need humans and animals have for a tactile interaction with each other that appears to be related to pleasure. This relationship has the strong potential to contribute to positive neurological development as a consequence.

One of the most significant ways that animals have been used to assist children is through animal assisted interventions. Equine-assisted interventions (EAIs) offer a unique approach in that they provide body to body contact, mastery in the handling of a large animal as well as a challenging interaction in an enriched rural environment. For instance therapeutic riding programmes have demonstrated effectiveness increasing children's self-esteem and self-confidence (R. Cawley, D. Cawley, & Retter, 1994; Taylor, 2001), reducing acting out behaviour in adolescents (Ewing, MacDonald, Taylor, & Bowers, 2007; Mallon, 1992; Trotter, 2006) and anger in boys (Kaiser et al., 2006), providing an alternative for trauma recovery for a rider (Yorke, 2003; Yorke, Adams, & Coady, 2008) and serving as a conduit for other therapies (Brooks, 2006; Taylor, 2001; Trotter, 2006; Tyler, 1994).

It may be that the equine–human relationship is an essential part of why equine-assisted therapy is effective. EAIs may offer ways to provide the key ingredients that alter neuro-physiological responses and establish new neuronal pathways that can contribute to sustained healing, healthy attachment in relationships and general well-being (Curtis & Cicchetti, 2003; Odendaal, 1999, 2000; Perry, 2006; Yasko, 1985). Such interventions may be especially useful for traumatised children who are neuro-physiologically dysregulated, providing an attunement with another being that soothes through touch, proximity and the development of trust (Yorke et al., 2008).

The neurological impact of human–animal relationships for trauma in children

Neurobiological techniques like human–animal interaction have the potential to stimulate, pushing activation around the brain in a sophisticated manner, similar to what happens in early interactive experiences between infants and caregivers (Amini et al., 1996; Carter, 1998; Corter & Fleming, 1995; Fleming, O'Day, & Kraemer, 1999;

Johnson, 2000; Odendaal, 1999; Shiloh et al., 2003). The consequence of this interaction may also mimic the impact of anti-depressant medication without the risks and side effects that might occur with children who have experienced trauma (Perry, 2002; Van der Kolk, 2003). As experience-dependent responses, children's regulatory limbic circuits may react rapidly to animal interactions responding to proximity, touch, warmth and responsiveness. The ventral system (v-PFC) becomes activated, along with the hippocampus and amygdala in response to these novel experiences (interaction with an animal) in the environment. The OFC and the ACC are activated (seeking systems) and the dorsal lateral PFC responds. They may address simultaneously the kindled response of anxiety or fear systems which produce cortisol but modulate or regulate that response by activating the synaptic paths in the ACC and hypothalamus. This activates the production of opioids that are calming, responding to the warmth, touch and proximity of another being (Figure 1). This process may mediate event-related potentials from the ACC and could impact personality changes that have developed through differences in emotional regulation, circumventing the potential for increased anxiety particularly if human-animal interaction is available to buffer stressful events (Odendaal & Meintjes, 2003; Perry, 2002; Todd & Lewis, in press; Van der Kolk, 2003).

Emotion is said to be regulated by touch and emotion regulates stress responses through the OFC, mediated by the ventral system (v-PFC). The OFC is an important epicentre for human-animal relationships because of the role it plays in both emotion and reward. Todd and Lewis (in press) notes that the OFC focuses on the rewards gleaned from the environment, building on processes associated with the cortical limbic interface, and in particular, the role of the OFC in synaptic development and pruning. 'Such rewards include those related to attachment and social bonding'

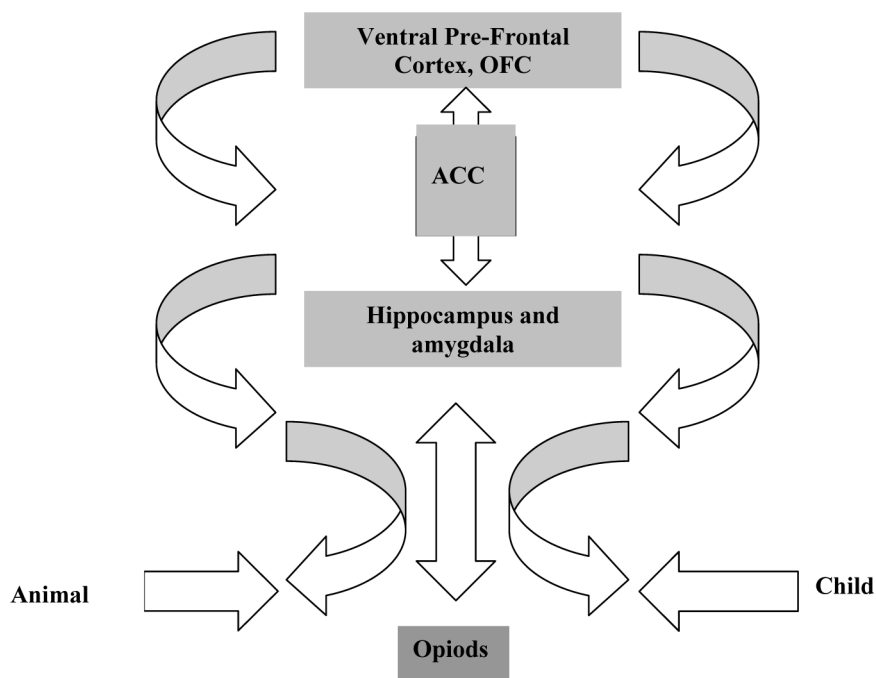


Figure 1. Synergistic effect of animal-child interaction.

(Tucker, Luu, & Derryberry, 2005 in Todd & Lewis, in press). Synaptic development and change in developmental processes relies on these kinds of interactions. Johnson (2000) notes that cortical specialisation can result from ‘... a wide variety of visual stimuli ...’ (p. 77). Neurobiological research indicates that emotion facilitates cognition and human animal interaction appears to provide the kind of emotional stimulation that contributes to synaptic shaping during periods of neuro-plasticity. Animals may provide a warm and secure interaction that may be more predictable than other relationships, particularly in stressful or chaotic environments where abuse or neglect is likely to occur.

Conclusion

If human–animal relationships are to be considered affective tools for intervening in stress or trauma responses in children, the role they play in activating pleasure and reward centres in the developing brain is the key to understanding how. The role that attachment plays in infant and consequently childhood cortical development is clear from the research discussed here. The research indicates that the role that human–animal attachment can play in cortical development relies on the length and intensity of the relationship as well as the capacity of the animal to be responsive. Children who swim with dolphins from a very early age may form different relationships from those who are interacting with the large friendly family dog from birth. Some research suggests that attachment to animals plays an important role in the development of empathy later in life (Daly & Morton, 2006; Melson, Peet, & Sparks, 1992). Melson (2003) contends that ‘children may cast their pets as functional younger siblings, as peer playmates, as their own “children” or even as a security-providing attachment figure’ (p. 37). If human–animal relationships provide infants and children with highly interactive and responsive interactions that are consistent, non-judgmental and hence rewarding, it is worthwhile exploring the clinical potential they have for augmenting cognitive behaviour approaches to neural development at important junctures in neuro-plasticity. Research needs to focus on the role of the ACC, the OFC as well as the PFC and the relationship human–animal interaction has with these aspects of developmental neurobiology.

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Note

1. The author acknowledges that interspecies interaction is a burgeoning field in neurobiology. This article has reviewed both animal and human developmental neurobiology, as well as the scant literature in interspecies neurobiology. Inferences are based on the evidence amassed in developmental neurobiology across all mammals.

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References

- Ainsworth, M.D. (1970). Attachment, exploration and separation: Illustrated by the behavior of one year olds in a strange situation. *Child Development*, 41(1), 49–67.
- Amini, F., Lewis, T., Lannon, R., Louie, A., Baumbacher, G., McGuinness, T., et al. (1996). Affect, attachment, memory: Contributions toward psychobiologic integration. *Psychiatry*, 59, 213–239.
- Antonucci, T.C., & Akiyama, H. (1994). Convoys of attachment and social relations in children, adolescents, and adults. In K. Hurrelmann & F. Nestmann (Eds.), *Social networks and social support in childhood and adolescence* (pp. 37–52). Berlin/New York: Aldine de Gruyter.
- Bowlby, J. (1969). *Attachment and loss*: (Vol. 1). New York: Basic Books.
- Bredy, T.W., Humpartzoomian, R.A., Cain, D.P., & Meaney, M.J. (2003). Partial reversal of the effect of maternal care on cognitive function through environmental enrichment. *Neuroscience*, 118, 571–576.
- Brooks, S.M. (2006). Animal-assisted psychotherapy and equine-assisted psychotherapy. In N. Boyd-Webb (Ed.), *Working with traumatized youth in child welfare* (pp. 196–218). New York: Guilford Press.
- Caldji, C., Diorio, J., & Meaney, M.J. (2000). Variations in maternal care in infancy regulate the development of stress reactivity. *Biological Psychiatry*, 48, 1164–1174.
- Carter, C.S. (1998). Neuroendocrine perspectives on social attachment and love. *Psychoneuroendocrinology*, 23(8), 779–818.
- Cawley, R., Cawley, D., & Retter, K. (1994). Therapeutic horseback riding and self-concept in adolescents with special educational needs. *Anthrozoös*, 7(2), 129–134.
- Corter, C.M., & Fleming, A.S. (1995). Psychobiology of maternal behavior in human beings. In M.H. Bornstein (Ed.), *Handbook of parenting: Biology and ecology of parenting* (pp. 87–116). Mahwah, NJ: Lawrence Erlbaum.
- Crawford, E.K., Worsham, N.L., & Swinehart, E.R. (2006). Benefits derived from companion animals and the use of the term ‘attachment’. *Anthrozoös*, 19(2), 98–112.
- Curtis, W.J., & Cicchetti, D. (2003). Moving research on resilience into the 21st century: Theoretical and methodological considerations in examining the biological contributors to resilience. *Development and Psychopathology*, 15, 773–810.
- Daly, B., & Morton, L.L. (2006). An investigation of human-animal interactions and empathy as related to pet preference, ownership, attachment, and attitudes in children. *Anthrozoös*, 19(2), 113–127.
- Di Pellegrino, G., Fadiga, L., Fogassi, L., Gallese, V., & Rizzolatti, G. (1992). Understanding motor events: A neurophysiological study. *Experimental Brain Research*, 91, 176–180.
- Elbert, T., Heim, S., & Rockstroh, B. (2001). Neural plasticity and development. In C.A. Nelson & M. Luciana (Eds.), *Handbook of developmental cognitive neuroscience* (pp. 191–202). Cambridge, MA: Bradford/MIT.
- Ewing, M., MacDonald, P., Taylor, M., & Bowers, M. (2007). Equine-facilitated learning for youths with severe emotional disorders: A quantitative and qualitative study. *Child Youth Care Forum*, 36, 59–72.
- Fleming, A.S., O’Day, D.H., & Kraemer, G.W. (1999). Neurobiology of mother–infant interactions: Experience and neuroplasticity across development and generations. *Neuroscience and Biobehavioral Reviews*, 23, 673–685.
- Francis, D.D., & Meaney, M.J. (1999). Maternal care and the development of stress responses. *Current Opinion in Neurobiology*, 9, 128–134.
- Friedmann, E., Katcher, A.H., Thomas, S.A., Lynch, J.J., & Messent, P.R. (1983). Social interaction and blood pressure: The influence of animal companions. *Journal of Nervous and Mental Disease*, 171, 461–465.
- Glaser, D. (2000). Child abuse and neglect and the brain – a review. *Journal of Child Psychology and Psychiatry*, 41(1), 97–116.
- Greenough, W.T., & Black, J.E. (1992). Induction of brain structure by experience: Substrates for cognitive development. In M.R. Gunnar & C.A. Nelson (Eds.), *Minnesota symposium on child psychology, 24: Developmental behavioral neuroscience* (pp. 155–200). Hillsdale, NJ: Lawrence Erlbaum.

- Hart, L. (2000). Psychosocial benefits of animal companionship. In *Handbook on animal assisted therapy: Theoretical formulations and guidelines for practice* (pp. 59–78). New York: Academic Press.
- Howe, M., & Lewis, M.D. (2005). The importance of dynamic systems approaches for understanding development. *Developmental Review, 25*, 247–251.
- Iacoboni, M., & Mazziota, J.C. (2007). Mirror neuron system: Basic findings and clinical applications. *Annals of Neurology, 62*, 213–218.
- Johnson, M.H. (1998). The neural basis of cognitive development. In W. Damon (Ed.), *Handbook of child psychology* (pp. 1–49). New York: Wiley.
- Johnson, M.H. (2000). Functional brain development in infants: Elements of an interactive specialization framework. *Child Development, 71*, 75–81.
- Kaiser, L., Spence, L.J., Lavergne, A.G., & Vanden Bosch, K.L. (2004). Can a week of therapeutic riding make a difference? – A pilot study. *Anthrozoös, 17*(1), 62–72.
- Kaplan, J.T., & Iacoboni, M. (2006). Getting a grip on other minds: Mirror neurons, intention understanding and cognitive empathy. *Social Neuroscience, 1*, 175–183.
- Katcher, A.H., & Wilkins, G. (1997). Dialogue with animals: Its nature and culture. In S.R. Kellert & E.O. Wilson (Eds.), *The biophilia hypothesis* (pp. 173–197). Washington, DC: Island Press.
- Kramer, P.D. (1993). *Listening to prozac*. New York: Viking.
- LeDoux, J. (1996). *The emotional brain: The mysterious underpinnings of emotional life*. New York: Simon & Schuster.
- Levitt, M.J. (2005). Social relations in childhood and adolescence: The convoy model perspective. *Human Development, 48*, 28–47.
- Lewis, M.D. (1995). Cognitive-emotional feedback and the self-organization of developmental paths. *Human Development, 38*, 71–102.
- Lewis, M.D. (2005a). Bridging emotion theory and neurobiology through dynamic systems modeling (target article). *Behavioral and Brain Sciences, 28*, 169–194.
- Lewis, M.D. (2005b). Self-organizing individual differences in brain development. *Developmental Review, 25*, 252–277.
- Lewis, M.D., & Todd, R. (2007). The self-regulating brain: Cortical–subcortical feedback and the development of intelligent action. *Cognitive Development, 22*, 406–430.
- Liu, D., Diorio, J., Tannenbaum, B., Caldji, C., Francis, D., Freedman, A., et al. (1997). Maternal care, hippocampal glucocorticoid receptors, and hypothalamic-pituitary-adrenal responses to stress. *Science, 277*, 1659–1662.
- Mallon, G.P. (1992). Utilization of animals as therapeutic adjuncts with children and youth. A review of the literature. *Child and Youth Care Forum, 21*, 53–67.
- Melson, G.F. (2003). Child development and the human-companion animal bond. *American Behavioral Scientist, 47*, 31–39.
- Melson, G.F., Peet, S., & Sparks, C. (1992). Children's attachment to their pets: Links to socio-emotional development. *Children's Environment Quarterly, 8*, 55–65.
- Nelson, C.A. (2000). Neural plasticity and human development: The role of early experience in sculpting memory systems. *Developmental Science, 3*, 115–136.
- Oberman, L.M., Ramachandran, V.S., & Pineda, J.A. (2008). Modulation of μ suppression in children with autism spectrum disorders in response to familiar or unfamiliar stimuli: The mirror neuron hypothesis. *Neuropsychologica, 46*(5), 1558–1565.
- Odendaal, J.S.J. (1999). A physiological basis for animal-facilitated psychotherapy. PhD thesis, University of Pretoria, 1994. *Dissertation Abstracts International, 56*, 11b, 00001.
- Odendaal, J.S.J. (2000). Animal-assisted therapy – Magic or medicine? *Journal of Psychosomatic Research, 49*, 275–280.
- Odendaal, J.S.J., & Meintjes, R.A. (2003). Neurophysiological correlates of affiliative behaviour between humans and dogs. *Veterinary Journal, 165*, 296–301.
- Panksepp, J. (1998). *Affective neuroscience: The foundations of human and animal emotions*. New York: Oxford University Press.
- Perry, B. (2002). Childhood experience and the expression of genetic potential: What childhood neglect tells us about nature and nurture. *Brain and Mind, 3*, 79–100.
- Perry, B. (2006). Applying principles of neurodevelopment to clinical work with maltreated and traumatized children. In N.B. Webb (Ed.), *Working with traumatized youth in child welfare* (pp. 27–52). New York: Guilford Press.

- Phillips, H. (2003). The pleasure seekers. *New Scientist*, 180(2416), 36–40.
- Prato-Previde, E., Custance, D.M., Spiezio, C., & Sabatini, F. (2003). Is the dog-human relationship an attachment bond: An observational study using Ainsworth's strange situation. *Behaviour*, 140, 225–254.
- Putnam, F.W. (2005). The developmental neurobiology of disrupted attachment: Lessons from animal models and child abuse research. In L.J. Berlin, Y. Ziv, L. Amaya-Jackson, & M.T. Greenberg (Eds.), *Enhancing early attachments: Theory, research, intervention and policy* (pp. 79–99). New York: Guilford Press.
- Reichert, E. (1998). Individual counseling for sexually abused children: A role for animals and storytelling. *Child and Adolescent Social Work Journal*, 15(3), 177–185.
- Rolls, E.T. (1999). *The brain and emotion*. Oxford: Oxford University Press.
- Schore, A. (2003). *Affect dysregulation and disorders of the self*. New York: W.W. Norton.
- Shiloh, S., Sorek, G., & Terkel, J. (2003). Reduction of state anxiety by petting animals in a controlled laboratory environment. *Anxiety, Stress and Coping*, 16(4), 387–395.
- Strand, E. (2004). Interparental conflict and youth maladjustment: The buffering effect of pets. *Stress, Trauma and Crisis*, 7, 151–168.
- Taylor, S. (2001). *Equine facilitated psychotherapy: An emerging field*. Unpublished master's thesis, St. Michael's College, Burlington, VT.
- Todd, R.M., & Lewis, M.D. (In press). Self-regulation in the developing brain. In J. Reed & J.W. Rogers (Eds.), *Child neuropsychology: Concepts, theory and practice*.
- Trotter, K.S. (2006). *The effectiveness of equine-assisted group counseling with at-risk children and adolescents*. Paper presented at the American Counseling Association International Conference and Hawaii International Conference on Education.
- Tucker, D.M., Luu, P., & Derryberry, D. (2005). Love hurts: The evolution of the empathic concern through the encephalization of nociceptive capacity. *Development and Psychopathology*, 17, 699–713.
- Turella, L., Pierno, A.C., Tubaldi, F., & Casteillo, U. (In press). Mirror neurons in humans: Consisting or confounding evidence? *Brain and Language*.
- Tyler, J. (1994). Equine psychotherapy: Worth more than just a horse laugh. *Women and Therapy*, 15, 139–146.
- Van der Kolk, B. (2003). The neurophysiology of childhood trauma and abuse. *Child and Adolescent Psychiatric Clinics*, 12, 293–317.
- Virues-Ortega, J., & Bruela-Casal, G. (2006). Psychophysiological effects of human–animal interaction: Theoretical issues and long-term interaction effects. *Journal of Nervous and Mental Disease*, 194(1), 52–57.
- Wilson, C.C. (1991). The pet as an anxiolytic intervention. *Journal of Nervous and Mental Disease*, 1(79), 482–489.
- Yasko, J.M. (1985). Holistic management of nausea and vomiting caused by chemotherapy. *Topics in Clinical Nursing*, 7(1), 26–38.
- Yehuda, R., & LeDoux, J. (2007). Response variation following trauma: A translational neuroscience approach to understanding PTSD. *Neuron*, 56, 19–32.
- Yorke, J. (2003). *The therapeutic value of the equine–human relationship in recovery from trauma: A qualitative analysis*. Masters thesis, Wilfrid Laurier University, Waterloo, Ontario.
- Yorke, J., Adams, C., & Coady, N. (2008). Therapeutic value of equine–human bonding in recovery from trauma. *Anthrozoös*, 21(1), 17–30.

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