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Making the World Safe for our Children: Down-regulating Defence and Up-regulating Social Engagement to 'Optimise' the Human Experience

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The Polyvagal Theory helps us understand how cues of risk and safety, which are continuously monitored by our nervous system, influence our physiological and behavioral states. The theory emphasizes that humans are on a quest to calm neural defense systems by detecting features of safety. This quest is initiated at birth when the infant needs for being soothed are dependent on the caregiver. The quest continues throughout the lifespan with needs for trusting friendships and loving partnerships to effectively co-regulate each other. The Polyvagal Theory proposes that through the process of evolution, social connectedness evolved as the primary biological imperative for mammals in their quest for survival. Functionally, social connectedness enabled proximity and co-regulation of physiological state between conspecifics starting with the mother-infant relationship and extending through the lifespan with other significant partners. The theory explains why feeling safe requires a unique set of cues to the nervous system that are not equivalent to physical safety or the removal of threat. The theory emphasizes the importance of safety cues emanating through reciprocal social interactions that dampen defense and how these cues can be distorted or optimized by environmental and bodily cues.

■ **Keywords:** Polyvagal Theory, neuroception, social engagement system, social behavior, co-regulation, safety

The Quest for Safety in a Dangerous World

Opportunities to feel safe are critical to human development (Bowlby, 1953). However, in place of cues of safety, cues of danger continuously invade the environments in which we work, recreate, attend school and raise our children. Even our homes are not immune to this barrage of negativity. Classrooms, clinics and communities are bombarded everyday with news of the devastating effects of dangerous environments on quality of life and health. Newspapers, magazines, radio, television and internet inundate us with descriptions of ruthless attacks in public areas, lost airplanes, kidnapped children, mass murders in schools, planned terrorist attacks, consequences of global warming, and the unpredictable devastation of earthquakes and floods. Against this background of violence, many family units experience spousal and child abuse, and children may be bullied through physical intimidation or humiliated through social media (Pinheiro, 2006). The chronic exposure to these risks degrades processes from cell to society and compromises the maintenance of health and the development of children (Molnar, Gortmaker, Bull, & Buka, 2004). It also affects not only health, but also educational achievement and the quality of social relationships. Children from high-risk environments exhibit aggressive and oppositional behaviours, lack the adaptive resources required to regulate their behaviour in social settings, and perform poorly in the structured academic environment. These psychologically toxic environmental features contribute to a causal pathway that limits a child's developmental trajectory (Shonkoff et al., 2012).

'Toxic load' is frequently discussed as a stressor of our immune system in the context of chronic exposure to environmental chemicals that may be carcinogenic. However,

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chronic negatively also creates *psychologically* toxic environments and the cumulative effects of these environments are less frequently discussed. Children exposed to chronic danger have an increased incidence of behavioural problems, learning delays, mental health issues and illness (Berens & Nelson, 2015). Demographic studies show that, with maturation, individuals from these high-risk environments have increased rates of incarceration, substance abuse, addiction, chronic illness and shorter life expectancy (Felitti et al., 1998; Flaherty et al., 2009; Shonkoff & Phillips, 2000). Although these findings are well documented, we know little about the mechanisms or processes through which danger and risk express their devastating effects.

Language and science offer only limited descriptions or definitions of safety. We have a limited vocabulary to describe safe places and feelings of safety. Externally, we do not elaborate on the features of safety, but focus on minimising features of danger. Internally, we tend not to consider feeling 'safe' as an emotion, mood or affective state. Researchers in the affective sciences – psychology and psychiatry – do not focus on the mechanisms mediating safety or the subjective and bodily responses associated with feeling safe, and have missed exploring this pre-eminent experience of adaptive success. Instead of investigating the attributes of feeling safe and the features that regulate these attributes, researchers have focused on vague constructs like 'stress' that are assumed to reflect the accumulated effect of internalising the negative features in the environment that trigger danger and fear.

We live in a culture that chiefly defines safety as the exclusion of risk from injury. Studies provide little information to operationally define safety, other than as an absence of the frequently quantified features of danger. Moreover, our view of safety is embedded in contemporary attitudes that often confuse safety with visible displays of law and order and the punitive treatment of those make us feel 'unsafe'. We are more focused on managing those who threaten or hurt us, than on understanding what our nervous system needs to feel safe. Yet, it is clear that having armed guards in elementary schools or even arming teachers is not equivalent to making a child feel safe in the school.

This emphasis on the features of danger neglects the profound sensitivity that humans have to features of safety and how exposure to these features can promote development and foster resilience. Safety is critical in enabling humans to optimise their potential in several domains. Safe states are a prerequisite not only for optimal social behaviour, but also for accessing the higher brain structures that enable humans to be creative and generative. Thus, it is not merely the removal of features of danger, but the active presentation of features of safety that our nervous system craves.

Seeking Features of Safety

For optimal health and growth, our nervous system expects features of safety to be present. But what features inform our nervous system that we are safe? Do our institutions – such as schools, government offices and medical treatment centres – have features that promote states of safety? An understanding of the biobehavioural need for safety has not informed the design of the structures and functional operations of institutions that provide direct services to people. For example, hospitals and educational institutions minimise opportunities for direct face-to-face interaction with service users and students, replacing or mediating these interactions with screens and computers. Schools proudly celebrate the shift from face-to-face teaching to the face–object teaching that computers offer. Medical centres celebrate the use of patient databases and computerised medical records that physically shift the orientation of the physician from patient to monitor. Without caring face-to-face interactions that include cues such as warmly modulated voices, the patient or student shifts rapidly into a bodily state that supports defence and limits the ability to understand the information words convey, such as information about diagnoses and treatment options or task instructions.

While we can reflect on the costs to human potential of living in a seemingly unsafe world, we might also begin to consider the importance of social interactions in enabling us to feel safe. Powerful changes are possible if social behaviour has the opportunity to promote a sense of safety. Effective social interactions may actively dampen defence systems and, when defence is down-regulated, our physiological state provides neural opportunities for us to learn and to form strong social bonds while simultaneously supporting health, growth and restoration.

Polyvagal Theory: Linking Safety to Social Behaviour and Health

This paper introduces Polyvagal Theory (Porges, 1995, 2001, 2007, 2009, 2011) as an innovative model that links the mechanisms mediating feelings of safety to social behaviour and health. Polyvagal Theory helps us understand how cues of risk and safety, which are continuously monitored by our nervous system, influence our physiological and behavioural states. The theory emphasises that humans are on a quest to calm neural defence systems by detecting features of safety. This quest is initiated at birth when an infant's need to be soothed is dependent on the care giver. The quest continues throughout the lifespan with emerging needs for trusting friendships and loving partnerships. This quest forms the motivation to develop social relationships that enable individuals to effectively co-regulate each other.

Often, ineffective substitutes replace social interactions as the primary mechanism to down-regulate the neural defence systems. These ineffective substitutes may manifest through clinical disorders, such as substance abuse and eating disorders, or maladaptive behaviours, such as compulsive work or exercise. Polyvagal Theory explains why feeling safe requires a unique set of cues to the nervous system that are not equivalent to physical safety or the removal of threat.

The theory emphasises both the importance of safety cues emerging from reciprocal social interactions that dampen defence, and how these cues can be distorted or optimised by environmental and bodily cues.

Connectedness: A Biological Imperative

A biological imperative is a construct frequently used in evolutionary biology to describe a plausible mechanism for natural selection. Biological imperatives are requisite functions that a living organism must fulfil to survive. Frequently described biological imperatives include territoriality, competition and reproduction. Perhaps the most familiar expression of the biological imperative for survival is 'survival of the fittest', which Darwin (1859) used to describe the mechanism of natural selection. Most interpretations of 'fittest' as applied to mammalian evolution tend to emphasise aggressive strategies. However, there are alternative interpretations, such as Dobzhansky's proposal that 'the fittest may also be the gentlest, because survival often requires mutual help and cooperation' (Dobzhansky, 1962).

Through the process of evolution, connectedness evolved as the primary biological imperative for mammals in their quest for survival. Functionally, social connectedness enabled proximity and co-regulation of the physiological state between conspecifics (members of the same species), beginning with the mother–infant relationship and extending through the lifespan to other significant partnerships.

Phylogeny, or the evolutionary history of species, is a central principle of Polyvagal Theory. Fundamental to phylogeny is the proposition that animals of different species descend from common ancestors. Relevant to human evolutionary history is vertebrate phylogeny. Humans, as mammals, form part of the class of vertebrates. Polyvagal Theory focuses, in particular, on the phylogenetic transition from ancient reptiles to mammals. The theory is not inclusive of modern reptiles or avian species that diverged from reptiles after mammals. Based on our phylogenetic history, mammals evolved from ancient reptiles that had several behavioural and physiological features similar to those of turtles.

Although Polyvagal Theory discusses biobehavioural responses as having adaptive function, the theory does not assume that these adaptive responses were the driving mechanisms for natural selection. It is possible that the biobehavioural responses that contribute to social and emotional communication were not direct adaptive products of selective pressure, but were by-products of the evolution of other characteristics. In contrast, evolutionary psychology assumes human psychological traits to be direct products of natural selection. Thus, Polyvagal Theory is agnostic to the critical premise underlying evolutionary psychology.

From a behavioural perspective, the examination of the phylogenetic transition from ancient reptiles to mammals identifies the unique functions of social behaviour in mammals as a potent, or indeed prepotent, regulator of physiology. The most obvious illustration of this transition is observed in the mother–infant relationship. In reptiles, the mother–infant relationship is extremely limited. Reptiles lay their eggs and leave the eggs to hatch. When the eggs hatch, the infant reptiles are dependent upon their own resources to survive. Functionally, the maternal role in ancient reptiles was limited to laying fertilised eggs and, in some circumstances, placing the eggs in a safe environment (for example, by burying them in sand). In contrast to the lack of social and physical contact between mothers and their offspring in ancient reptiles, infant mammals are dependent on their mothers for several aspects of survival, including thermal regulation, food and protection. In many situations, the 'mother' may not be the biological mother or even a female. More importantly, this mother or care giver needs to be available to reliably provide the infant with opportunities of high-quality reciprocal interactions.

While these processes nurture the infant, the interactions with the mother also serve as *neural exercises* that enable social cues of safety, emanating from the mother, to regulate the infant's physiology and behavioural state. As the infant calms, cues from the infant calm the mother. These bidirectional and reciprocal interactions strengthen the social bonds between mother and infant and foster a capacity to co-regulate. These features of co-regulation between mother and infant form the prototype for social relationships through the child's lifespan. Functionally, the experiences of the infant in the mother–infant relationship provide opportunities for neural exercises to strengthen pathways that will enable social behaviour to regulate physiological state. If these neural pathways are adequately exercised, the ability to co-regulate with another is optimised. If these neural pathways are inadequately exercised, or the opportunities to co-regulate with the mother are disrupted or unreliable, then as the child matures the ability to co-regulate with another is at risk.

The Role of the Vagus in Bidirectional Communication

During the phylogenetic transition from ancient reptiles to mammals, the autonomic nervous system changed. In the ancient reptiles, the autonomic nervous system regulated bodily organs via two subsystems: the sympathetic nervous system and the parasympathetic nervous system. Modern reptiles share these global features. The sympathetic nervous system provides the neural pathways for visceral changes that support fight and flight behaviours. The sympathetic nervous system functions to support mobilisation by increasing heart rate and suppressing digestion. Complementing the sympathetic nervous system, the reptilian parasympathetic nervous system serves two functions. First, it supports processes of health, growth and restoration. Second, when recruited as a defence system, the parasympathetic nervous system reduces metabolic activity by dampening heart rate and respiration, enabling immobilised reptiles to appear inanimate to potential predators. When not under threat the two components of the autonomic nervous system in reptiles function antagonistically and simultaneously innervate several of the body organs to support bodily functions.

Most of the neural pathways of the parasympathetic nervous system travel through the vagus. The vagus is a large cranial nerve that originates in the brainstem and connects visceral organs with the brain. In contrast to the nerves that emerge from the spinal cord, the vagus connects the brain directly to bodily organs. The vagus contains both motor fibres to change the function of visceral organs and sensory fibres to provide the brain with continuous information about the status of these organs. The flow of information between body and brain informs specific brain circuits that regulate target organs. Bidirectional communication provides a neural basis for a mind–body science, or brain–body medicine, by providing plausible portals of intervention to correct brain dysfunction via peripheral vagal stimulation (for example, vagal nerve stimulation for epilepsy) and plausible explanations for exacerbation of clinical symptoms by psychological stressors, such as stress-related episodes of irritable bowel syndrome. In addition, bidirectional communication between the brain and specific visceral organs provides an anatomical basis for historical concepts within physiology and medicine, such as Walter Cannon's *homeostasis* (Cannon, 1932) and Claude Bernard's *internal milieu* (Bernard, 1872).

In vertebrates other than mammals, the vagus originates in a brainstem area known as the dorsal nucleus of the vagus. During the evolutionary transition from ancient reptiles to mammals, a second vagal motor pathway emerged that originated in the nucleus ambiguus, a brainstem area ventral to the dorsal nucleus of the vagus. Although the vagal pathways originating in nucleus ambiguus are the primary motor pathways regulating the heart, the nucleus ambiguus is also part of a brainstem column that regulates the striated muscles of the face and head. These emergent changes in neuroanatomy provide a face–heart connection in which there are mutual interactions between the vagal influences to the heart and the neural regulation of the striated muscles of the face and head.

The phylogenetically novel face–heart connection provided mammals with an ability to convey physiological state via facial expression and prosody (intonation of voice), enabling facial expression and voice to calm physiological state. Functionally, the face–heart connection enabled mammals to detect whether a conspecific was in a calm physiological state and 'safe' to approach, or in a highly mobilised and reactive physiological state during which engagement would be dangerous. The face–heart connection concurrently enables an individual to signal 'safety' through patterns of facial expression and vocal intonation, and potentially calm an agitated conspecific to form a social relationship. Thus, the theory is named 'polyvagal' to emphasise changes in the neuroanatomy of the vagus that parallel changes in social behaviour.

Myelination and the Regulation of Bodily Organs

Mammals have two vagal pathways – myelinated and unmyelinated. In common with other vertebrates, mammals have unmyelinated vagal motor fibres originating in the dorsal nucleus of the vagus. However, unique to mammals are myelinated vagal motor fibres originating in the nucleus ambiguus. These myelinated vagal fibres are a major regulator of heart rate by inhibiting the heart's pacemaker. In mammals, approximately 80% of the vagal fibres are sensory (Berthoud & Neuhuber, 2000). Of the 20% that are motor, the vast majority are unmyelinated. Myelinated vagal motor fibres originating in the nucleus ambiguus account for about 3% of the total vagal fibres.

Myelin is a substance composed primarily of fat (approximately 70–85% lipid) that forms a sheath around nerve fibres. Myelin electrically insulates the nerve and enables neural transmission to be selective and rapid. The process of myelination of vagal motor fibres in humans begins during gestation at approximately 28 weeks and continues at a rapid rate during the last trimester. Vagal fibres continue to myelinate following birth, with the percentage of myelinated vagal fibres reaching levels similar to those of adults at approximately 1 year of age (Sachis et al., 1982). A critical function of the myelinated vagus is its ability to down-regulate sympathetic excitation and support the calm biobehavioural states necessary for social interactions (Porges & Furman, 2011).

The primary functions of the two vagal motor pathways are different. The vagal motor fibres originating from the dorsal nucleus of the vagus are the primary regulators of organs below the diaphragm (stomach, intestines, uterus, prostate, bladder, colon, pancreas, gall bladder, liver, kidneys), while the vagal motor fibres originating in nucleus ambiguus are primary regulators of organs above the diaphragm (for example, the heart and bronchi). In the brainstem, the nucleus ambiguus is located ventral to the dorsal nucleus of the vagus and is often referred to as the ventral vagus. Note that the presence of motor fibres in the vagus, which originate in each brainstem nuclei, can only be confirmed through experimental procedures such as histology (evaluating the diameter of the fibres and the degree of myelination) or electrical stimulation (evaluating the impact on the target organ).

The Centrality of the Autonomic Nervous System to Polyvagal Theory

There are two features of the mammalian autonomic nervous system that serve social behaviour and form the basis of the Polyvagal Theory. First, the areas that regulate the ventral vagal pathways to the heart are integrated in the brainstem with the neural pathways that regulate the striated muscles of the face and head. This face–heart connection forms an integrated Social Engagement System that provides and senses signals of safety. Second, the reactivity of the autonomic nervous system is hierarchical, with the ventral vagal pathways inhibiting the sympathetic activation, and the sympathetic nervous system capable of inhibiting the dorsal vagal pathways to the subdiaphragmatic organs. These two facts, based on neuroanatomy and neurophysiology, transform Polyvagal Theory from a neurobiological description to a theory that generates testable hypotheses relating physiological states to mental health, social behaviour and emotional regulation.

Polyvagal Theory describes how each of three phylogenetic stages in the development of the vertebrate autonomic nervous system is associated with a distinct autonomic subsystem that is retained and expressed in humans and other mammals. These autonomic subsystems are phylogenetically ordered and behaviourally linked to social communication (facial expression, vocalisation, listening), mobilisation (fight–flight behaviours) and immobilisation (feigning death, fainting, behavioural shutdown and dissociation).

Dissolution

The three autonomic circuits are organised and respond to challenges in a phylogenetically determined hierarchy that is consistent with the Jacksonian principle of dissolution (Jackson, 1958). Jackson proposed that, in the brain, higher (i.e., phylogenetically newer) neural circuits inhibit lower (i.e., phylogenetically older) neural circuits, and 'when the higher are suddenly rendered functionless, the lower rise in activity'. Although Jackson proposed dissolution to explain changes in brain function due to damage and illness, Polyvagal Theory proposes a similar phylogenetically ordered hierarchical model to describe the sequence of autonomic response strategies to challenges.

When the nervous system evaluates the environment as being safe, two important features are expressed. First, bodily state is regulated in an efficient manner to promote growth and restoration (visceral homeostasis). This is done through an increase in the influence of mammalian myelinated vagal motor pathways on the cardiac pacemaker that slows the heart, inhibits the fight–flight mechanisms of the sympathetic nervous system, dampens the stress response system of the hypothalamic–pituitary–adrenal (HPA) axis (e.g., cortisol), and reduces inflammation by modulating immune reactions (e.g., cytokines). Second, through the process of evolution, the brainstem nuclei that regulate the myelinated vagus were integrated with the nuclei that regulate the muscles of the face and head. This link enables a bidirectional coupling between spontaneous social engagement behaviours and bodily states. Thus, as mammals evolved, an integrated Social Engagement System emerged that enabled social behaviour to regulate physiological state.

The human nervous system, similar to that of other mammals, evolved not solely to survive in a safe environment, but also to survive in dangerous and life-threatening contexts. To accomplish this adaptive flexibility, the human nervous system retained two more primitive neural circuits to regulate defensive strategies (i.e., fight–flight and death-feigning behaviours). It is important to note that social behaviour, social communication and visceral homeostasis are incompatible with the neurophysiological states and behaviours promoted by the two neural circuits that support defence strategies. Thus, via evolution, the human nervous system retains three neural circuits, which are in a phylogenetically organised hierarchy. In this hierarchy of adaptive responses, the newest circuit is used first; if that circuit fails to provide safety, the older circuits are recruited sequentially.

The Face–Heart Connection: The Emergence of the Social Engagement System

Social communication and the ability to co-regulate the biobehavioural state are defining features of mammals. These features are dependent on phylogenetic emergence of the neural communication between the face and the heart. With these neural connections, physiological state is signalled by changes in the face and voice. In humans, these easily observed manifestations in voice and face define emotions and parallel dynamic changes in affective state (mood). While emotions and mood are reliable concepts within psychology and psychiatry, they are quantified by subjective reports of mental state and objective measures of observable behaviours, and not by measures of physiology. The Polyvagal Theory proposes that physiological state is a fundament part, and *not* a correlate, of emotion and mood. The theory emphasises a bidirectional link between brain and viscera, which would explain both how thoughts can change our physiology, and how physiological state influences our thoughts. As individuals change their facial expressions and voices, they are also changing their physiology.

The Social Engagement System involves the myelinated vagus, which serves to foster calm behavioural states by inhibiting sympathetic influences to the heart and dampening the HPA axis. The mobilisation system is dependent on the functioning of the sympathetic nervous system. The most phylogenetically primitive component, the immobilisation system, is dependent on the unmyelinated vagus. With increased neural complexity resulting from phylogenetic development, the organism's behavioural and affective repertoire is enriched. The three circuits can be conceptualised as dynamic, providing adaptive responses to safe, dangerous, and life-threatening events and contexts.

Neuroception and Safety

To switch effectively from defensive to social engagement strategies, the mammalian nervous system performs two important adaptive tasks: (1) assess risk; and (2) if the environment is safe, inhibit the more primitive limbic structures that control fight–flight or immobilisation behaviours. The central nervous system, through the processing of sensory information from the environment and from the viscera, continuously evaluates risk. Since the evaluation of risk is so important to survival, much of the evaluation is going on in areas of our brain that are outside of consciousness. This process is not equivalent to perception, which is frequently linked to conscious awareness. Thus, the term *neuroception* was introduced to emphasise a neural process, distinct from perception and sensation, capable of distinguishing environmental (and visceral) features that are safe, dangerous or life-threatening (Porges, 2004). If neuroception detects features of safety, autonomic state is adaptively regulated to dampen defence.

As a neural process, neuroception enables humans and other mammals to engage in social behaviours by distinguishing safe from dangerous contexts. Neuroception is a plausible mechanism mediating both the expression and the disruption of positive social behaviour, emotion regulation and visceral homeostasis. Neuroception might be triggered by feature detectors involving areas of cortex that communicate with the central nucleus of the amygdala and the periaqueductal grey, since limbic reactivity is modulated by temporal cortex responses to the intention of biological movement, including variations in tonal quality of voice, facial expression, and movements of head and hands. Thus, the neuroception of familiar individuals and individuals with appropriately prosodic voices and warm expressive faces translates into a social interaction that down-regulates defence and enables feelings of safety.

Optimally, the nervous system evaluates risk and matches neurophysiological state with the actual risk of the environment. When the environment is appraised as being safe, the defensive limbic structures are inhibited, enabling social engagement and calm visceral states to emerge. However, some individuals, especially children who experience trauma and abuse, experience a mismatch; the nervous system appraises the environment as dangerous even when it is safe. This mismatch results in physiological states that support defensive strategies (i.e., fight–flight or immobilisation), but not social engagement. According to Polyvagal Theory, only when defence circuits are inhibited can social communication be expressed efficiently through the Social Engagement System.

Social Communication for Co-regulation

Environmental cues that elicit feelings of safety have the potential to recruit the evolutionarily more advanced neural circuits (e.g., ventral vagal pathways) that support the prosocial behaviours of the Social Engagement System. For example, a mother's voice has the capacity to sooth her infant. As the infant listens to the mother's melodic vocalisations, 'feature' detectors in the infant's brain interpret the voice as reflecting the mother's state as calm and her presence as safe and supportive. This sequence is not learned, but an evolved adaptive process that enables social signals to regulate biobehavioural state.

The sounds of the mother's vocalisation signal safety, which is detected by higher brain structures. The higher brain structures dampen defence systems and facilitate the calming effect on the heart by ventral vagal influences. In parallel to this calming effect, the regulation of the muscles of the face and head are enhanced to enable reciprocal interactions between mother and infant. The reciprocal interactions function as a neural exercise between their Social Engagement Systems. The result is an infant–mother dyad that efficiently uses social communication to co-regulate, with both participants feeling calm and bonded. This process functions as a neural exercise that builds capacity for the infant to develop relations with others and to deal with state regulation challenges and disruptions through the lifespan.

In all cultures, the presentation of prosodic acoustic stimulation, whether vocal or instrumental, is an effective strategy for signalling safety and calming infants. Elements of this strategy are incorporated in music and have been understood intuitively by classical composers. In fact, the opening movements of several classical symphonies mimic the acoustic features of the lullabies that mothers sing to their children. Similar calming effects of prosodic vocalisations are observed across other mammalian species, in which prosodic vocalisations are effective indicators of safe intentions. This is understood intuitively by many when talking to their dog or cat, although the same people may be less aware of their vocal intonations when talking to their children or significant others.

The features of risk in the environment do not solely drive neuroception. Afferent feedback from the viscera provides a major mediator of the accessibility of prosocial circuits associated with social engagement behaviours. For example, Polyvagal Theory predicts that states of mobilisation compromise our ability to detect positive social cues. Functionally, visceral states distort or colour our perception of others. Thus, the features of a person engaging another may result in a range of 'neuroceptive' outcomes, depending on the physiological state of the target individual. If the person being engaged is in a state in which the Social Engagement System is easily accessible, a reciprocal prosocial interaction is likely to occur. However, if the individual is in a state of mobilisation, the same engaging response might be responded to with asocial features of withdrawal or aggression. In such a state, it might be difficult to dampen the mobilisation circuit to enable the Social Engagement System to come back on line.

The Influence of Sensory Feedback from the Organs below the Diaphragm

Not all sensory feedback is related to mobilisation states. Sensory feedback from the organs below the diaphragm is potent and frequently occurs during illness and injury. Unlike the specificity of sensory feedback we get through spinal nerves when we are cut, burned or bruised, our brain interprets the sensory 'interoceptive' signals from the subdiaphragmatic organs as generalised, and, other than a general feeling of malaise, it is often impossible to identify the source of the signal to our brain (Craig, 2002; Porges, 1993).

During illness, injury, inflammation or any profound challenge to the normal 'homeostatic' function of a visceral organ, signals travel from these organs through the sensory branch of the vagus to a brainstem area labelled 'nucleus of the solitary tract'. This nucleus functions as a central regulator of a feedback system that regulates visceral organs. As the primary sensory nucleus of the vagus, it sends information to both vagal 'motor' nuclei (nucleus ambiguus and dorsal nucleus of the vagus) to selectively modulate specific target organs.

When focusing on mobilisation as a defence (i.e., fight–flight behaviours), vagal afferent pathways via the nucleus of the solitary track impact on the nucleus ambiguus, enabling the efficient expression of sympathetic activation by turning off the inhibitory action of the myelinated 'ventral' vagal pathways on the heart (i.e., removing the 'vagal brake') (Porges, Doussard-Roosevelt, Portales, & Greenspan, 1997). However, when focusing on immobilisation as a defence, the vagal sensory pathways via the nucleus of the solitary tract activate the dorsal nucleus of the vagus. Thus, trauma inflicted directly upon the subdiaphragmatic area (via surgery, birthing, rape, illness or injury), may trigger dorsal vagal responses that are manifested psychologically as depression or dissociation, behaviourally as fatigue, and medically as problems in blood pressure regulation, fainting, fibromyalgia or digestive disorders, including irritable bowel syndrome.

Discrepancy between Feelings and Cognitions

Neuroception emphasises that neural processes involved in risk evaluation are not conscious. Functionally, this results in a disconnection between conscious perceptions and feelings. We are aware of our feelings, but we are not aware of the antecedent features in the environment that trigger the neuroceptive processes that change our physiological state and form the neural substrate of our feelings. For example, a change in the tone of a person's voice to a lower tone with less prosody may trigger a neuroceptive response associated with fear responses to a predator. The words may be benign, but the tonal qualities of voice may trigger a physiological state that supports aggressive behaviours (Koizumi et al., 2011). During these states higher brain processes attempt to make sense of the discrepancy between feelings and cognitions. In most situations, the feelings take priority because the feelings are wired in our brain to adaptive survival strategies. Once feelings drive our defences, our higher brain structures build a cohesive personal narrative that justifies being defensive. However, if we do not overreact (by experiencing a tantrum), there is the possibility of developing an understanding that specific feelings in our body represent states of vulnerability. With this understanding we can be informed to make behavioural adjustments to calm our physiology before we continue attempts to socially engage. When we are in these physiologically vulnerable states, our attempts to socially engage may be expressed as aggressive, and we might misinterpret the social cues of others as aggressive. In vulnerable people, even subtle behavioural changes, such as mild exercise or walking, may reduce the calming influence of the vagal brake and put the individual into a state in which they are at risk for misinterpreting social engagement behaviours as aggressive.

Regardless of age, the vulnerability of the Social Engagement System to environmental cues of danger and life threat is profound. Even with the removal of danger cues, the Social Engagement System may remain dormant unless it is appropriately stimulated with safety cues. Research with infants of depressed mothers illustrates that the lack of opportunity for reciprocal interactions changes the emotional and social profile and trajectory of the infant. For the Social Engagement System to function, the cues of interaction that are processed by both the visual (facial expressions, gestures) and auditory (prosodic vocalisations) systems are critical. This redundancy of sensory domains (i.e., visual and auditory) enables cues of safety to regulate the child, even if there is damage to one of these sensory systems. Although gentle tactile cues may also communicate cues of safety, they are often preceded by prosodic voice or warm facial expressions. Without the antecedent vocal and facial signalling of safety, even gentle touch may trigger a neuroceptive state of danger and the child may recoil from the touch.

The emergence of the Social Engagement System provides humans with the opportunity to use social behaviour to co-regulate physiological state and to symbiotically experience a biobehavioural state of safety. It is during this mutually shared state of feeling safe that the expansive capacities of the human experience can be optimised. The Social Engagement System functions as a bidirectional conduit between the sensory cues from others and the motor systems that express the products of our thoughts and feelings. Although this *conduit of connectedness* can efficiently down-regulate defensive physiological states through the potent features of voice and face, the conduit is vulnerable to the diffuse and potent sensory stimuli coming from our bodily organs. Thus, engagement behaviours may be relatively inefficient in calming when directed at an individual who is in a physiological state that supports defence. Under these conditions facial expressions and syntax may be misinterpreted and, instead of calming, may elicit aggression.

However, the auditory channel may be more accessible in regulating state. The prepotent influence of a mother's voice in calming a fussy infant is a demonstration of this effect. It is highly unlikely that the mother's smile would be sufficient to sooth the child.

Mammalian Projection of Physiological State through Voice

The production of vocalisations that convey emotion (i.e., prosody) and the ability to detect these sounds evolved in parallel with the changes in the mammalian autonomic nervous system (Stewart et al., 2013, 2015). During the phylogenetic transition that produced the two vagal circuits in mammals, the uniquely mammalian vagal circuit evolved to provide a parallel output to laryngeal muscles that mediate vocal prosody. When the vagus calms the heart, the beat-to-beat heart rate pattern becomes more systematically periodic. In parallel with the vagal calming of the heart, vagal regulation of the laryngeal muscles produces more prosodic (i.e., variable) lower-pitched sounds. When the vagal inhibition (vagal brake) is withdrawn from the heart, vocalisations have a higher pitch with little variability. This convergence between the neural control of the heart and the neural regulation of the laryngeal muscles provided conspecifics with the ability to express physiological state in intonations of voice. When in a mobilised state, they would have a low threshold to react with aggressive behaviours, heart rate would be higher and the variability of heart rate mediated by vagal influences would be reduced. In parallel, vocalisations would sound shrill due to an increase in dominant pitch and less variable tonal qualities.

In parallel to the changes in vagal regulation (and expansion of the cortex) that occurred in the phylogenetic transition from ancient reptiles to mammals, the middle-ear bones detached from the jawbone. The neural regulation of the muscles that stiffen and relax the middle ear bone is controlled by nerves that originate in the brainstem area that controls the 'mammalian' vagus (Porges & Lewis, 2009). When these nerves tense the middle-ear muscles, higher frequency sounds associated with social communication are transmitted with greater clarity to the brain. When the muscles relax, the lower frequency sounds that are phylogenetically related to predator become predominant and mask the tonal features of social communication. Thus, when we are in a 'vagal' state of calmness, the middle ears promote the processing of the vocalisations (more prosodic intonations) that signal safety.

Functionally, the neural regulation of the middle-ear structures enabled mammals to hear soft sounds that were produced at a higher pitch than the acoustic range of reptiles could process. Reptiles can only process lower pitch sounds, since their middle-ear bones were still part of the jawbone. When mammals initially evolved, they were small and reptiles were their primary predators. In this hostile environment, mammals had a 'bandwidth' in which they could communicate without being detected by reptiles. To survive, mammals need to co-regulate and need to be in close proximity to each other. Vocalisations fulfilled an adaptive function of signalling safety to their infants and to conspecifics. Listening is therefore an active process that requires regulation of middle-ear muscles.

The convergence between the neural regulation of laryngeal and middle-ear muscles provided mammals with mechanisms to signal and to detect acoustic cues in vocalisations of safety and danger. Thus, mammals, not only had the ability to express bodily state in voice, but also had a uniquely mammalian middle ear that functionally dampened low-frequency background noise and enabled the processing of specific acoustic cues of social communication (Porges & Lewis, 2009; Porges et al., 2014; Stewart et al., 2013, 2015).

Summary

Polyvagal Theory proposes that the evolution of the mammalian autonomic nervous system provides the neurophysiological substrates for adaptive behavioural strategies. It further proposes that physiological state limits the range of behaviour and psychological experience. The theory links the evolution of the autonomic nervous system to affective experience, emotional expression, facial gestures, vocal communication, selective listening to vocalisations and contingent social behaviour. The theory provides a plausible explanation for the reported covariation between atypical autonomic regulation (e.g., reduced vagal and increased sympathetic influences to the heart) and psychiatric and behavioural disorders that involve difficulties in regulating appropriate social, emotional and communication behaviours. Polyvagal Theory provides several insights into the adaptive nature of physiological state. First, the theory emphasises that physiological states support different classes of behaviour. For example, a physiological state characterised by a vagal withdrawal would support the mobilisation behaviours of fight and flight. In contrast, a physiological state characterised by increased vagal influence on the heart (via myelinated vagal pathways) would support spontaneous social engagement behaviours. Second, the theory emphasises the formation of an integrated Social Engagement System through functional and structural links between neural control of the striated muscles of the face and the smooth muscles of the viscera. Third, Polyvagal Theory proposes a mechanism—neuroception—to trigger or to inhibit defence strategies.

Polyvagal Theory is an innovative model that links the mechanisms mediating feelings of safety to social behaviour and health. It helps us understand how cues of risk and safety, which are continuously monitored by our nervous system (neuroception), influence our physiological and behavioural states. The theory emphasises that humans are on a quest to calm neural defence systems by detecting features of safety. This quest is initiated at birth when the infant needs for soothing are dependent on the mother. The quest continues throughout the lifespan, with needs for trusting friendships and loving partnerships. This quest forms the motivation to develop social relationships that enable partners to effectively co-regulate each other.

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