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The Infant's Sixth Sense: Awareness and Regulation of Bodily Processes

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Life is a sensory experience. During every moment of our life we experience the world through our varied sensory systems. Sensory experiences drive our behavior and contribute to the organization of our thoughts and emotions. Immediately after birth, the infant is bombarded with a variety of new sensory stimuli. These provide important information about the characteristics and potential demands of the baby's new environment. The infant must immediately detect, discriminate and adapt to this information. Successful adaptation to the rapidly changing environment and the ability to cope with changing demands depend on the infant's ability to detect and interpret sensory information. Thus, when we study infant behavioral patterns, vocalizations and physiological reactivity, we attempt to understand how the young infant uses sensory systems to detect information from the environment, and to integrate this information into motor, affective and cognitive schema to successfully interact with the environment.

We have learned that humans have five primary sense modalities: smell, vision, hearing, taste and touch. We know that even a newborn can respond to smell, vision, hearing, taste and touch. These responses are obvious to the parent and clinician (although only a few decades ago, scientists were unaware of many sensory capacities of young infants). However, this traditional method of categorizing sensory information does not account for the vast amount of sensory information being conveyed to the brain from the numerous sensors located inside our body. Even current clinical models of infant regulation (e.g., Greenspan, 1992; Ayres, 1972) that emphasize the importance of sensory processing in the emotional and cognitive development of the infant, and individual differences among infants in the ease with which they detect and interpret sensory information, focus primarily on three sense modalities that describe the external

environment — that is, touch, vision, and hearing. These models do not deal with internal sensations that provide information about the physiological regulation.

Although neurophysiologists and neuroanatomists describe sensory systems which regulate our internal organs, this research has had little influence on either our common language or the clinical terminology we use to describe bodily processes. At present, there are only a few easily understood descriptors that characterize internal senses and states — for example, pain, nausea and arousal. Yet, in spite of this linguistic handicap, our experiences provide us with an awareness of bodily sensations and an appreciation of how these sensations can contribute to mood state and psychological feelings.

Missing from our language and our science is the ability to describe internal states. In our day-to-day interactions we choose vague terms, such as "feelings" to describe the psychological consequences of bodily changes. Behavioral scientists often attempt to objectify these terms by operationalizing concepts such as state, mood, and emotion with verbal reports and elaborate coding systems. Clinical practitioners infer these feelings and use terms descriptive of emotional tone. However, whether we are talking about feelings, emotions, states, or moods, we are always attempting to describe the internal states that are continuously being monitored and regulated by the nervous system.

The goal of this article is to introduce an additional sense modality that monitors bodily processes. A variety of terms may be used to describe this sensory system. Classic physiology describes this sensory system as **interoception**. Interoception is a global concept which includes both our conscious feelings of and unconscious monitoring of bodily processes. Interoception, like other sensory systems, has four components:

1. Sensors located in various internal organs to "sense" internal conditions;
2. Sensory pathways that convey information to the brain regarding the internal conditions;
3. Brain structures to interpret sensory information and organize systems to respond to the changing internal conditions; and
4. Motor pathways that communicate from the brain back to the internal organs that contain the sensors to change directly the state of the internal organ.

Brain structures evaluate interoceptive information, categorize it, associate it with other sensory information, and store the associations in memory.

Interoception is the sixth primary sense

The five classic senses described above are categorized based upon the sensors located on the external surface of the body, or exteroceptors. However, we are aware that the external senses (e.g., vision, audition, sound, touch, smell, and taste) are not the sole source of stimulation directing the infant's behavior, thoughts, and emotions. The ability to sense internal states and bodily processes — through interoceptors located on the heart, stomach, liver, and other organs inside the body cavity — constitutes a sixth sense that is crucial to the infant's survival.

This sixth sense represents a functional awareness, with both conscious and unconscious dimensions, of what is happening inside the body. For example, on a conscious level, digestive processes may provide sensory information that the infant interprets as hunger when the stomach is empty, or as pain when the stomach is severely distended due to gas. The cardiovascular and respiratory systems also provide conscious feedback. Alertness changes as a function of shifts in both blood pressure associated with posture (when, for example, a baby brightens when picked up and held upright against a parent's shoulder) and blood gas concentrations of carbon dioxide and oxygen. On an unconscious level, internal organs have sensors which send continuous information to brain structures. This unconscious awareness fosters stability (i.e., homeostasis) in internal physiology by rapidly adjusting to support specific motor behaviors and psychological processes.

Although bodily sensations are paramount to the infant's successful survival, developmental specialists are currently more concerned with the infant's capacity to sense external stimuli. For example, clinical assessment tools, such as neurological and neuropsychological examinations, focus only on the processing of external stimulation. Similarly, our current childrearing and intervention strategies are not at all geared to helping young children sense their internal physiological states. We do not provide infants and young children with descriptive or symbolic tools to represent internal states, nor are caregivers taught to perceive specific behavioral or physiological indicators of gradations in the infant's bodily sensations. This remains the case even though we know that the status of bodily functions (such as digestion) and infants' reactions to difficulties in these processes (such as colic) are derived via important sensory systems. Moreover, the sensory information from continuously monitoring bodily functions can influence the infant's ability to perform specific behaviors, perceive external stimuli, and organize information into mental representation of cognitions and emotions.



Evaluating sensory processing

For the five classic sensory modalities, we can evaluate the competence of the child to process sensory information by direct observation of behavior and through verbal reports. We can observe adaptive and dysfunctional strategies. We can identify problems by observing hypo-responsiveness and hyper-responsiveness in response to specific sensory challenges. We can evaluate developmental patterns in the child's ability to integrate sensory information. In addition, we can evaluate intervention procedures delivered by professionals such as speech and hearing specialists, ophthalmologists, nurses, occupational therapists, physical therapists, psychologists, psychiatrists, and pediatricians.

In contrast, interoceptive competence has not been systematized. Other than estimates of pain severity, there are no methods to quantify perception of bodily processes or to test unconscious interoceptive feedback. There are no scales to identify developmental landmarks.

But whether or not we know how to describe or measure them, sensations from inside the body are a strong influence on the infant's behavior in the world. From birth, the infant's need of sleep, food, water, and warmth are monitored via internal sensors. This information drives much of the infant's behavior. The infant's behavior then provides cues to the caregiver. In other words, stimulation of specific sensors inside the body of the young infant results in behavioral responses that prompt the caregiver to interact with the infant, to comfort and to reduce the cause of the bodily sensations. For

example, feeding the infant reduces hunger, burping relieves flatulence after feeding, and sucking may stimulate digestion and reduce constipation.

Interoception: The infrastructure of higher-order behavior

Interoception is dependent on a complex feedback system that starts with sensors located in various body organs and ends with the higher-order social interaction with the caregiver. Faulty sensors or a dysfunction in any component of the sensory system (i.e., sensor, sensory pathway to the brain, motor pathway from the brain, or areas in the brain that interpret the sensory information and control the motor output to the organ) may contribute not only to physiological problems, but also negatively impact on the psychological and interactive experiences of the infant. Thus, the quality of interoceptive processes may contribute to individual differences in information processing (e.g., cognitive processes), emotional expressiveness, and social behavior.

I have conceptualized the dependency of complex behaviors on successful bodily processing in a hierarchical model with four levels (see Porges, 1983). Each level requires successful functioning on the preceding level of organization. Although the model includes complex social behaviors, the substrate of the model depends on the organizational competence of the nervous system.

- Level I is characteristic of homeostatic processes of physiological systems regulating the internal organs. Homeostatic regulation requires the bidirectional interoceptive process of monitoring and regulating the internal organ via sensory and motor pathways between the brain and the internal organ.
- Level II processes require cortical, conscious, and often motivated influences on the brainstem regulation of homeostasis.
- Level III processes are observable behaviors that can be evaluated by the quantity, quality, and appropriateness of motor behavior.
- Level IV reflects the coordination of behavior, emotional tone, and bodily state to successfully negotiate social interactions.

This model assumes that complex behavior, including social interactions, depends on physiology and how appropriately the nervous system regulates bodily processes. In this model, interoception becomes the foundation of physical, psychological, and social development. Interoception serves as the neuro-physiological substrate of the higher processes, included in Level III and Level IV, that have been elaborated by many other researchers, practitioners, and theorists of child development.

Level I processes: Physiological homeostasis

Underlying the vague concept of "feelings" is a physiological process that depends upon interoception.

By explaining and measuring the functional regulation of physiological processes dependent upon interoceptive mechanisms, we can identify functional vulnerabilities in the infant's ability to regulate on the most basic level. If the infant is insensitive to his or her own bodily calls for care, nurturance, and protection, how will the infant appropriately function and respond to social needs?

Level I processes provide the physiological mechanisms for state regulation, including emotional regulation and expression. They also provide the infrastructure for the child's successful interaction with the challenging social demands of the world.

In the proposed hierarchical model, Level I processes represent the successful regulation of internal bodily process via neural feedback systems. To maintain homeostasis, interoceptors originating in the body cavity (e.g., gastric, hepatic, enteric, cardiac, vascular, and pulmonary systems) transmit information via nerves to brainstem structures. The brainstem structures interpret the sensory information and regulate the internal physiological organs. They do this by stimulating nerves that either directly control internal organs (e.g., increase or decrease heart rate, constrict or dilate blood vessels, inhibit or facilitate peristaltic activity, etc.) or indirectly manipulate the organs by releasing specific hormones or peptides (e.g., adrenalin, insulin, oxytocin, vasopressin, gastrin, somatostatin, etc.).

Level I is associated with the organization and neural feedback mechanisms that characterize the maintenance of homeostasis. These homeostatic processes can shut down when either internal conditions or external challenges require maximum output of energy. For example, fever, severe thermo-stress, extreme emotional distress, and aerobic exercise can reflexively inhibit Level I feedback systems. States associated with severe illness (e.g., physiological compromise and instability) are also characterized by a down-regulation of the neural control of bodily processes. Alternatively, up-regulation may occur when the interoceptors are directly stimulated (e.g., the filling of the stomach with food) or when other sensory modalities reflexively influence bodily processes. For example, the smell of appetizing food initiates signals from the nose to the brainstem structures that in turn stimulate glands in the mouth and stomach to produce digestive secretions even before the food enters the mouth.

Level II processes: Cost of doing business

The autonomic nervous system is the division of the nervous system that senses the condition of internal organs and regulates their activity. The autonomic nervous system deals with: 1) servicing the needs of the organs inside the body; and 2) responding to external challenges. We can define adaptive behavioral strategies and homeostasis in terms of the child's ability to trade-off between internal and external needs. Based upon this model, homeostasis and response strategies to environmental demands are interdependent. Homeostasis reflects the regulation of the physiological conditions within the body. Response

strategies reflect the stage when internal needs become less important than external needs — when the baby (fed, burped, and changed) is ready and eager to interact with the world of people and things.

The autonomic nervous system has two branches, the sympathetic and the parasympathetic. In general, the parasympathetic branch promotes functions associated with growth and restoration. In contrast, the sympathetic branch promotes increased output of energy to deal with challenges from outside the body. When there are no environmental demands, the autonomic nervous system services the needs of internal organs to enhance growth and restoration. However, in response to environmental demands, homeostatic processes are compromised and the autonomic nervous system supports increased output of energy, by down-regulating parasympathetic function and often stimulating sympathetic function to deal with these external challenges.

The central nervous system mediates the distribution of resources to deal with internal and external demands. Perceptions and assumed threats to survival (independent of the actual physical characteristics of the stimulation) may promote a massive withdrawal of parasympathetic tone and a reciprocal excitation of sympathetic tone. This trade-off between internal and external needs is monitored and regulated by the central nervous system.

Level II represents the integration of interoceptive systems with other sensory modalities and psychological processes. Unlike the reflexive integration described in Level I, Level II involves higher brain processes. Level II processes include voluntary approaches to the source of stimulation or an awareness of the need to problem solve and engage in information processing. To foster the contact with the stimulus or to process information, the internal bodily state is changed. Level II is characterized by the appropriate adjustment (i.e., gradations in inhibition) of homeostatic processes during states of attention, the processing of information, and social behavior.

When other senses — for example, hearing, sight, or touch — are stimulated, the autonomic responses are a secondary process. Under these conditions, after the baby detects sensory information, his brain structures regulate autonomic organs to facilitate the processing of the sensory information. These physiological states may support the baby's ability simply to pay attention to the sensory stimulus, or, by increasing metabolic output, the physiological state may support the child's physical movement towards or away from the stimulus.

Sensory information from the external environment triggers changes in internal regulation that are maintained via accurate interoception. Without accurate interoception, the down-regulation of internal physiological processes may compromise survival — for example, by inhibiting digestion or by disturbing electrolyte or blood gas levels. Defects in interoception may also be at the base of regulatory disorders (Greenspan, 1991). Regulatory disorders

reflect a broad spectrum of dysfunction in young children and include difficulties in bodily processes such as eating and sleeping, difficulties in processing sensory and affective information, and difficulties in state regulation.

Physiological and behavioral homeostasis: Parallel concepts

As a construct, physiological homeostasis is consistent with the behavioral homeostasis observed by Greenspan (1992). Greenspan has described a developmental period from birth to three months during which the infant masters homeostatic processes. In this model, homeostasis requires the appropriate regulation of sleep and behavioral states as well as the ability to incorporate appropriate visual, auditory, and tactile stimulation. Thus, children defined as having regulatory disorders have difficulties in sleep, feeding, and sensory integration.

Greenspan's model, however, focuses on the external sensory modalities — hearing, sight, and touch. I am suggesting that physiological homeostasis (Level I) and the regulation of physiological homeostasis to support sensory processing of environmental stimuli (Level II) are necessary substrates for the behavioral homeostasis. In



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other words, the regulatory disorders defined by Greenspan may have a physiological substrate (Porges & Greenspan, 1991). Empirical research provides support for this hypothesis (e.g., DeGangi et al., 1991; Portales et al., 1992; Porges et al., in press). We are demonstrating that physiological measures of homeostasis are related to behavioral problems in infants. Our findings suggest the possibility that clinicians will be able to use physiological measures that reflect interoceptive competence diagnostically, to identify Level I and Level II vulnerabilities in infants and young children.

Assessment of Level I and Level II processes

In general, homeostatic processes are regulated by the parasympathetic nervous system via the vagus nerve, a large nerve with several branches enabling bi-directional communication between brain structures and internal organs. The vagus, with its sensory and motor pathways, is the primary component of the interoceptive system. The vagus and its branches account for approximately 80 percent of the parasympathetic nervous system. Approximately 70 percent of the vagal fibers are sensory, and thus, directly service interoceptors within the body cavity. Thus, measurement of vagal activity provides information on interoception in maintaining homeostasis (i.e., Level I processes) and the regulation of homeostasis to support environmental challenges (i.e., Level II processes).

It is possible to monitor vagal activity by quantifying specific rhythmic changes in heart rate (see Porges, 1992). Level I processes may be evaluated by measuring vagal control of the heart during rest or sleep; this provides a measure of the infant's interoceptive capacities to maintain homeostatic control. Level II processes may be evaluated by measuring the change in vagal control of the heart during environmental challenges; this provides a measure of the infant's capacity to down-regulate the vagal system to deal with environmental demands.

Our research program provides data supporting the hypothesis that the ability to sense and regulate internal physiological state is at the base of competencies in higher-order behavioral, psychological, and social processes. Currently, we are developing laboratory procedures to profile the infant's capacity to regulate internal physiological systems during a variety of sensory processing demands. Our long-term goal is to provide a standardized clinical instrument to evaluate interoception. This instrument would complement neurological, neuropsychological, and other sensory evaluations. The assessment would index interoceptive processes through the measurement of heart vagal influences on the heart (i.e., cardiac vagal tone). The instrument will have the capacity to evaluate two dimensions of interoception:

1. The capacity to monitor and maintain homeostasis in the absence of environmental challenges (i.e. Level I processes); and
2. The capacity to alter homeostasis to support behaviors required by environmental challenges (i.e., Level II processes).

The ability to measure interoception, the sixth sense, opens a new window to the infant's sensory experiences. This window allows us to observe and to understand the internal feelings of the infant and how these internal states change during illness, mental processing, and social behavior. ♪

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