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CHAPTER

6

The Emergence of Emotion: Experience, Development, and Biology

SETH D. POLLAK

"For I regard human emotions and their properties as on the same footing with other natural phenomena. Assuredly human emotions indicate the power and ingenuity of nature, if not human nature, quite as fully as other things which we admire, and which we delight to contemplate."

(Spinoza, 1677/1957, p. 114)

A central assumption in the study of human emotion is that we are born with certain basic emotions (at least those referred to in Western cultures by words such as *anger*, *sadness*, *fear*, *disgust*, and *happiness*) and that some rudimentary neural circuitry for emotion is preconfigured in the human brain. Indeed, the predominant theories of emotion take as a core tenet that basic emotions are characterized by distinctive signatures of hormonal, muscular, autonomic, and subjective responses that are each coordinated to serve adaptive functions (e.g., Buck, 1999; Cosmides & Tooby,

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2000; Ekman, 1973, 1992; Izard, 1978, 1993; Ekman, Campos, Davidson, & de Waal, 2003; Johnson-Laird & Oatley, 1992; LeDoux, 2000; Levenson, 2003a,b; Panksepp, 2000; Plutchik, 1982). Often these theories include acknowledgment that influences such as the developing child's learning history may play a role in emotional responding (e.g., Ekman, 1992; Izard, Youngstrom, Fine, Mostow, & Trentacosta, 2006; Keltner & Haidt, 2001; Panksepp, 1998). In general, however, theories of emotional development either emphasize the hard-wired, universal aspect of emotion and devote little attention to learning processes, or they emphasize functional adaptations and underspecify the initial state of emotion in the brain that facilitates learning (Campos, Mumme, Kermoian, & Campos, 1994). In this chapter, I focus on a central question in human development: How do children manage to learn so much about emotion from the examples they see, hear, and experience? Are the emotional signals that children experience too vast and complex a system for children to learn from, or are emotions too inconsistent, unclear, or nuanced to support rapid learning and mastery without some guided predisposition for emotion learning? Whether or not emotional experiences are complex or vague, the reality is that most infants do learn an immense amount about emotions and master a complex social repertoire; yet we understand little about what guides this early learning. Here, I highlight different perspectives on the ontogenesis of emotion. Next, I examine data that are both in favor of and inconsistent with these arguments about the origin of emotion. I conclude by noting the ways in which translational research—both between basic and clinical as well as human and nonhuman studies—may help clarify the developmental mechanisms underlying emotion. Because emotional difficulties are central to all forms of mental health problems, a clear understanding of the origin and development of emotion holds tremendous promise for prevention and remediation of mental illness in children and adults.

WHAT IS THE INITIAL STATE OF THE EMOTIONAL BRAIN?

One view of the origins of emotions maintains that humans are genetically programmed to develop the circuitry that underlies basic emotional behaviors. Darwin (1872/1965), for example, argued that facial expressions are innate. By describing emotions as innate, Darwin meant that the ability to pose, express, and understand the meaning of facial expressions exists in the brain independent of any kind of sensory or learning experience. The most prominent contemporary theories about the ontogenesis of emotion, including those of Silvan Tomkins (1963), Carroll Izard (1991), and Paul Ekman (1994), begin with the basic premise that rudimentary or basic emotions are innate, discrete neurological packages with specific sets of predetermined bodily and facial reactions. These theories about emotion are grounded in a broader rubric called *nativism*, which refers to the view that certain skills or abilities are *native* or hardwired into the brain at birth.

Nativism emerges from a rich intellectual history in psychology, philosophy, and developmental biology. As it is applied to psychological phenomena, nativism stems from the seminal ideas of the philosopher David Hume. Hume (1748/1902) articulated a logical argument: People could not infer notions of causality based upon the perceptual input we receive from the world. Based upon what we actually observe, the most we could hope to infer from our perceptual experiences is that two events happen in succession. We could only reason that A preceded B or that A and B co-occur, but not that B resulted from A. What follows from Hume's argument is the conclusion that concepts such as the ability to understand causality must exist in the mind prior to any sensory or perceptual experience. The extension of this argument is that any psychological construct that organisms acquire, but that could not have been learned based upon sensory input, must be innate. Indeed, the philosopher Immanuel Kant, in his *Critique of Pure Reason* (1902), posited that from birth humans know certain things about objects that they could not have learned based upon their experiences in the world. One example of this type of knowledge is that all objects are successive over time and juxtaposed in space. Schopenhauer (1928) agreed with Kant that humans must have some innate knowledge, but he reduced the number of innate categories back down to the original one—namely, causality, which, he argued, presupposes all other domains of knowledge.

Modern psychology has greatly expanded the domains of knowledge hypothesized to be innate. Arguments in favor of innate knowledge in humans have been advanced for emotion (Ekman, 1999; Izard, 1997), physics (Spelke, 1999), causality (Leslie & Keeble, 1987), animacy (Carey, 1985), grammar (Chomsky, 1959/2003), face processing (Kanwisher, 2000), intentionality (Gergely & Csibra, 2003), numeracy (Dehaene & Cohen, 1997; Xu, Spelke, & Goddard, 2005), theory of mind (Leslie, 1987), attachment (Bowlby, 1988), and most recently social hierarchy (Zink et al., 2008). A related perspective that combines these views is that humans are born with *core knowledge* systems that represent inanimate objects and their mechanics, social agents and their goal-directed actions, numerical relationships, and spatial/geometric relationships (Spelke & Kinzler, 2007).

The contrasting view to nativism is empiricism. *Empiricism* holds that the innate capabilities of the brain do not contain content such as beliefs, knowledge, or specific packages of skills; instead, humans possess inborn capabilities for learning from the environment. This epistemological concept emphasizes the role of sensory experience as the basis of knowledge. The term *empiricism* has a dual etymology. The Latin translation is *experientia*, from which we derive the word *experience*; the word also derives from a more specific classical Greek usage of *empiric*, referring to a physician whose skill derives from practical experience as opposed to instruction in theory. Empiricism was explicitly formulated by John Locke (1709), who argued that the mind is a *tabula rasa* (*clean slate* or *blank tablet*), upon which experiences leave their marks. In this view, the human mind does not possess anything knowable without reference to experience in the sensory world. Any knowledge properly inferred or deduced must be gained from sense-based experience. Empiricism was historically contrasted with a school of thought known as *rationalism*, which, in very broad terms, asserted that knowledge derives from reason independent of the senses. However, this contrast is no longer meaningful. Indeed, the main rationalists (Descartes, Spinoza, and Leibniz) were also advocates of empirical methods.

NATIVISM AND EMOTION

There are many sound reasons to consider some aspects of emotion to be innate. The most frequently cited and compelling evidence is that distinct emotions are observed very early in the infant's life, with relatively little individual variation in form, function, and developmental timing. Although there is considerable debate about how to determine what an infant is feeling, it is clear that young infants demonstrate a surprising facility to acquire and use basic emotions.

Arguments supporting a nativist stance toward emotion typically include some variant of the following claims:

1. Other than in the case of certain neurological conditions, human infants acquire emotions early in life. Typically developing children express and recognize happiness, sadness, anger, fear, disgust, and surprise within the first postnatal year regardless of parental style, culture, or education. There is no evidence that children are explicitly taught to express or recognize emotions. By this, I mean that children are rarely instructed or corrected as to the right way to express an emotion; what children appear to be explicitly taught is when to suppress or mask emotional expressions rather than the pairing of elicitors, subjective feelings, and outward manifestation of emotional expressions.
2. Emotional development is fairly ordered with regularity in developmental timing that varies little across individuals or cultures. This overall stability in emotional development applies to children in vastly different circumstances. There appears to be a high degree of universality in the way humans recognize emotions, and even children born both blind and deaf—who could not have acquired expressions through observation or modeling—produce similar expressions of emotion as typically developing children (Eibl-Eibesfeldt, 1972).
3. Children's errors in emotional expression are rarely noticed by adults and errors in young children's emotion recognition and reasoning appear to be circumscribed and to follow predictable developmental patterns.
4. Basic emotions are universal, with similarities not only across species, but also across human cultures. For example, the signaling intentions of emotions, such as a smiling face as an indication of *welcoming*, are universally understood (Fridlund, 1994).

5. The emotional behaviors evinced by even very young infants may appear simple, yet they represent computationally complex processes linking perceptual information to conceptual and representational knowledge.

Both of the seminal and comprehensive theories of emotional development encompass the basic premises listed. Carroll Izard's (1978) Discrete Emotions Theory is based upon observations that emotional behaviors cohere in infancy, with similar patterns of vocal, facial, and postural reactions across infants to similar elicitors. In this view, discrete emotions are innate and invariant over the life span (Izard, 1984) and the innate qualities include expressions and emotion feelings (Izard & Malatesta, 1987). These basic emotions preempt consciousness and drive narrowly focused sets of responses (Izard, 1977; Tomkins, 1963). Developmental changes in this basic-emotion response system are attributed to learning after the infancy and toddler periods. Here, the innately specified emotion system can be modified or inhibited by cognitive and learned regulatory capacities, which can result in new emotions beyond the basic innate set.

Paul Ekman's (1972) Neocultural Theory posits two factors in emotional development. The first component consists of a small set of fundamental emotions that are innate, biologically based, and universal. By using the term *biological*, Ekman conveys his belief that these emotion processes, if unimpeded, will be expressed naturally as motor programs that include facial expressions such as smiles and frowns. The second component in this theory allows for cultural or social effects on emotional development and includes the display rules that children learn such as when and where each expression should be displayed, suppressed, or masked. The general principle of this theory is that it accommodates both innate and learned components in emotional development in that core emotions are posited to exist prior to sensory or social experience, but they are shaped or socialized according to cultural rules.

Although a comprehensive review of the literature on emotional development is not possible here, a limited sampling of data suggests that there is both merit to, and inconsistency with, nativist perspectives. Nativist theories are supported by observations that neonates preferentially attend to faces. Indeed, infants ranging from 2 to 8 months of age express more interest in a live human face than to a mannequin and more to the mannequin than to a face-shaped object with scrambled facial features (Morton & Johnson, 1991). Extant data suggest that this preference appears to be a general perceptual preference rather than a face- or emotion-specific orientation (for a review, see Turati, 2004).

Although, consistent with nativist theories, early research suggested that young infants responded to emotion-specific categories such as happiness and anger (e.g., Haviland & Lelwica, 1987). It is now understood that infants discriminate facial features such as an open mouth with visible teeth versus a closed mouth. Indeed, what first appeared to be evidence that infants held categories of basic emotional expressions turned out to be evidence that infants are perceptually sensitive to the presence of teeth. At 4, 7, and 9 months of age infants fail to discriminate happy from angry faces if the expressions both involve open mouths (Caron, Caron, & Myers, 1985).

By 3½ months of age, infants can demonstrate that they are aware of when facial expressions of emotion match vocal expressions of the same emotion, looking longer when the facial and vocal cues are mismatched (Kahana-Kalman & Walker-Andrews, 2001). This behavior suggests early appearance of a complex skill. However, it is curious that the 3-month-olds are only able to differentiate nonmatching emotional cues when the expressions are produced by the infant's own mother. Moreover, the ability of infants to accurately pair facial expressions of emotion with affectively concordant or discordant vocal expressions correlates with the amount of parent–infant contact time the infant has had (Montague & Walker-Andrews, 2002), suggesting an effect of learning or experience. By 1 year of age, infants are able to use facial cues produced by their caregivers to evaluate potential threat, as evidenced by *social referencing* behaviors (Sorce, Emde, Campos, & Klinnert, 1985; Klinnert, Emde, Butterfield, & Campos, 1986). Again, this is a computationally complex task that infants appear to be able to master quickly. Yet, as with other studies of emotion recognition, familiarity with the individual expressing an emotion enhances the infant's ability to extract information from that person's emotional expressions.

With regard to emotion production, the experience of both inoculation and goal blockage elicits anger expressions in 4-month-old infants

(Campos, 1996; Izard, Hembree, & Huebner, 1987). Moreover, infant anger and sadness expressions appear to be related to distinct patterns of autonomic nervous system and hypothalamic–pituitary–adrenal system activity (Lewis, Ramsay, & Sullivan, 2006). For example, 10-month-olds showed different patterns of electroencephalograph asymmetry (different right and left frontal activation) during anger and sadness expressions (Fox & Davidson, 1988). It should be acknowledged, though, that when scientists refer to *infant emotional expressions*, it is more precise to describe these behaviors as facial expressions that adult observers interpret as being indicative of underlying emotional states. Such caution highlights the difficulty in validating what a neonate is truly *feeling*. At the same time, it is problematic to require some sort of self-report of subjective feeling states as evidence of an emotion. If a self-report is required to *validate* the presence of an emotional state, then substantive nonhuman animal research on emotion would be excluded from consideration. Nonhuman animal research has been instrumental in furthering understanding of processes such as fear, aspects of depression, stress regulation, and emotional components of neurodevelopmental disorders in humans. Even among adults, self-reports of feeling states provide only one type of information. Reports about subjective feeling states may be informative for addressing how individuals introspect, attend to, or choose to describe their experiences and behaviors. Yet how research subjects say they might feel or respond or think in different situations cannot uncover biological mechanisms because research subjects do not have awareness of the neural processes involved in the processing of their emotional states. Moreover, traditional methods do not lend themselves to the kinds of experimental manipulations necessary to test precise hypotheses about how humans process emotional information (Pollak, Vardi, Bechner, & Curtin, 2005).

Much of the data used to support nativist claims can also be used to highlight a role for learning; however, it is also the case that studies used to support empiricist views can be interpreted from a nativist perspective. A significant role of learning is highlighted by the observation that children do not appear to use distinct categories of emotion until the age of 5 years, with younger children often relying upon labels such as *happy* and *sad* to describe broad categories of *positive* and *negative* emotions (Widen & Russell, 2003). Children slowly learn to differentiate within positive and negative categories until they have acquired concepts for anger, fear, and so on. Such findings raise two significant issues. First, the data on children's development of emotion concepts suggest that children's *errors* in labeling emotion faces and subjective feeling states are systematic rather than random. For example, children initially associate faces and labels largely on the basis of valence—positive versus negative (Bullock & Russell, 1984; Russell & Bullock, 1986). The presence of such systematicity or structure could be taken as evidence of rudimentary, innate emotion knowledge. Second, the overt behavioral performance of young children will necessarily be limited by children's abilities to meet the cognitive and motor demands of particular tasks. Thus, children's competence or conceptual knowledge may not be reflected in overt behavioral performance. Unfortunately, for these reasons, extant data are not sufficient to refute or confirm nativist or empiricist claims; rather, these data highlight the difficulty in supporting one claim over another.

In fact, there are many good reasons to consider that human infants enter the world with something that starts, directs, or facilitates emotional development. What extant data do not adequately address is precisely the nature of those primary building blocks. Darwin (1872/1965) was not studying emotions as we think of them today; rather, he was specifically interested in emotional expression as evidence for evolution. In many respects, Darwin was an exemplar of a translational scientist in that he was attempting to understand emotion expression by contrasting adult, child, and nonhuman animal behavior as well as using both normal and atypical phenomena to inform each other. In his early writings, Darwin described emotional expression as a reflex-like mechanism that was triggered involuntarily. For example, he focused on behaviors such as the raising of the lips that we perceive as a grimace, snarl, or baring of teeth and associate with a response to threat or an expression of hostility. Certain expressions such as eyebrow raising upon greeting, laughter, and crying, and bared teeth paired with wrinkled brows during anger, are seen across cultures (Eibl-Eibesfeldt, 1972; Ortony & Turner, 1990). This type of inborn, reflex-like aspect of emotion noted by Darwin is the type of behavior that Izard and Ekman try to capture as innate, biologically based, and universal. Left uncertain is what the relationship is between a reflex and an underlying representation for an emotion.

EMPIRICISM AND EMOTION

From an empiricist approach, the basis of nativistic arguments consists almost exclusively of assumptions. Indeed, a conceptual problem rarely addressed in the literature on emotion development concerns how the presence of an innate emotion, or innate mechanism of emotional development, could be empirically tested or falsified. At some level, nativistic theories may appear unfalsifiable because there are no fixed criteria for when abilities are innate. Typically, innate is equated with *appearing early in development*, and what appears early in ontogeny is assumed to reflect processes that appear early in phylogeny (e.g., Buck, 1999; Damasio, 1999; Darwin, 1872/1965; Dimberg, Thunberg, & Elmehed, 2000; Ekman, 1994; Izard, 1971; Langer, 1967; Lundqvist & Öhman, 2005; Öhman & Mineka, 2001; Panksepp, 2000; Plutchik, 1982).

This situation reflects what Putnam (1967) called a *what else* argument. By this, Putnam means that there is no positive evidence for any kind of innate mechanism. Rather, we evoke the *infants are born with it* position as the most parsimonious account of behavioral data that lacks an otherwise adequate explanation. This is not unsound reasoning; it merely requires that scientists acknowledge the difference between hypothesized explanations that seem to fit with what we observe about children's emotional behavior as compared with the epistemological status of a developmental claim that has been empirically tested. The predominant theories of emotional development follow the *parsimony* line of reasoning: Given what we observe in human infants, *what else* could account for emotional development other than an innate origin?

In response, the general principles of empiricist accounts are usually some variant of the following argument:

1. It is plausible that there is enough sensory input in the world to learn complex phenomena.

2. Sensory input has an organizing role on brain systems early in development.
3. Nativist theorists may drastically underestimate the power of the human infant's learning abilities.

Empiricist claims raise questions about the soundness of premises used in the formulation of nativist accounts. The first issue is concerned with at what point it could be claimed that a human infant has had absolutely no experience with emotion. Consider that within a few moments of postnatal life a human infant has been exposed to a wide array of emotional experiences such as smiles, laughter, touch, and cries—there is certainly no void of human emotional behavior immediately after childbirth! It is a mistake to consider 3- to 6-month-old babies as proxies for organisms without experience. A strong version of the empiricist view of emotion is that environmental factors play a critical role in the emergence of basic emotions, not just in the refinement, modification, or socialization of emotions. On this view, it is possible that similar forms of early learning in infants could lead observers to the assumption that a feature of emotional development is innate when in fact it was learned quickly and early in development. This is a conceptually complex issue, however, in that equally valid questions can be raised about why sensory input regarding emotion is consistent enough to structure learning similarly across organisms.

Second, although it is true that many forms of complex emotional behaviors appear very early in infancy, the observation that a behavior emerges early in life is not proof that the behavior is innate. Even verification that a behavior or skill is *present at birth* is insufficient to conclude it is innate because some behaviors may be present early in development but are clearly not innate. Neonates show perceptual preferences for their mother's native language (Mehler, Jusczyk, Lambertz, & Halsted, 1988) and for stories that were read aloud during their mother's pregnancy (DeCasper & Spence, 1986). These behaviors are clearly learned. Similarly, pre- and perinatal events can have lasting effects on the mature structure of the immune system by altering the trajectory of immune cells (Hodgson & Coe, 2006). Humans do not have molars in the back of our mouths at birth, yet the process of growing teeth and the eventual location of different types of teeth in our mouths is innately specified. The point here is that many aspects of development may be present at birth but still learned or may not be present at birth yet still reflect innate processes, including the growing of teeth, the emergence of pubic hair during puberty, or genetic diseases for which symptoms do not appear until later in life. These examples highlight that the developmental timing of the emergence of a behavior, regardless of how early or late in life the behavior appears, is inconclusive with regard to determining experience-independence.

Evidence of cross-cultural invariance in emotional development is often used to bolster nativist theories. However, cross-cultural similarities in emotional behavior are not inconsistent with an empiricist perspective. For example, there is some debate about whether scientists have generally underestimated the variance in emotional behavior both within and between cultures (Barrett, 2006; Elfenbein & Ambady, 2002; Scherer, Johnstone, & Klasmeyer, 2003). Furthermore, it is possible that developing infant brains are responsive to features of sensory input that are relatively constant across human social environments. For example, although humans may display significant behavioral differences across cultures, at some level, humans might treat neonates similarly. These basic similarities across human behavior, which may escape the attention of adults, could serve as learning cues for infants. Indeed, if one posits powerful learning mechanisms in infancy, then even an infant who is only a few months, weeks, days, or hours old has already had opportunities to be exposed to sensory input from the environment.

Fourth, although nativist theories of emotion suggest that each emotion should be a discrete neural *package*, there has yet to be consistent brain-imaging data that suggest a clear biological signature for any discrete emotion. Barrett and Wager (2006) summarize the ways in which functional neuroimaging studies fail to support biological plausibility for innate emotion systems. For example, one of the most widely cited examples of an emotion–brain pairing is that fear is associated with activation of the amygdala (Murphy, Nimmo-Smith, & Lawrence, 2003; Phan, Wager, Taylor, & Liberzon, 2002).Yet Phan and colleagues (2002) reported that only 60% of studies involving fear showed increased activation in the amygdala, and Murphy and colleagues (2003) reported that only 40% of published functional studies of the amygdala find support for this association. There is good evidence from the animal literature that some fear-related behaviors such as freezing depend on specific nuclei in the amygdala and brainstem (e.g., LeDoux, 2000; Panksepp, 1998). However, none of the behaviors associated with these groups of neurons are associated with any single emotion.

In sum, observation that a behavior appears early in development does not provide sufficient data to conclude that the behavior is innate. It is not clear that people feel or experience emotions similarly across cultures (or even across individuals) or what underlying brain mechanisms might constitute an innate emotion system. As will be discussed later in this chapter, translational research that includes not only typically developing children, but also atypical populations of children and emotional behaviors in nonhuman animals, may help clarify these issues.

NATIVISM AND DOMAIN GENERALITY

The distinction between strong claims of nativism and empiricism is a useful heuristic at one level. Yet these distinctions set up a false dichotomy that does not capture the beliefs of most scientists working in the area of emotional development. Emotion theorists acknowledge that learning occurs over development and few contemporary scientists would maintain that the infant brain has no structure at all. Neurologically healthy children learn to speak, perform numerical computations, attend to faces, recognize inanimate objects, maneuver the physical world, and achieve bipedal locomotion. Therefore, the substantive developmental questions include the following.

1. How can we characterize the initial state of emotion in the human brain prior to sensory experience?
2. How can we characterize is the processes through which that initial state is transformed into mature knowledge and behavior?

Nativistic theories provide a more satisfying response to the first question in that empiricist theories posit the initial state of the infant emotional brain to include only a mechanism for learning. In other words, empiricist theories tend to answer the first issue (initial state) by responding to the second issue (mechanism of change). In this way, it is easy to confound questions about the initial state of the organism with issues about the developmental mechanisms that support change and learning of emotion. Empiricist theories better address the issues of developmental change that hold importance for understanding how to best support, augment, and remediate issues in children's emotional development. In this regard, nativist theories tend to gloss over the ways in which humans can learn so much about the world based upon relatively little evidence and how initial states of knowledge can be expanded into mature representations. It is not the case that nativists see individuals as somehow *fixed*, but it is simply that with so much attention paid to the initial state of the organism, subsequent maturation receives scant attention. Simply put: If everything arrives hard-wired, why and how does change occur? Similarly: Whether or not the infant is born with some rudimentary form of basic emotion, the infant still faces a formidable learning problem in mastering emotional communication.

Given that both nativist and empiricist theories must allow for the infant brain to have some starting point as well as the ability to grow and mature, the differences between the approaches concern the quantity, extensiveness, and type of structures attributed to the initial state of the brain on a continuum. At one end of the continuum, there may be few innate ideas, principles, or mechanisms. These sorts of theories tend to posit very general developmental mechanisms that support learning across numerous domains. Therefore, there is more weight placed on the organizing structure of environmental input combined with a powerful role of sensory and perceptual systems. By contrast, theories at the other end of the spectrum view the brain as highly differentiated, with numerous specialized systems. In these views, the brain is composed of more innate elements that include learning systems that are specific to these particular hypothesized domains of development. Again, however, notice that in this typical kind of characterization of nativist and empiricist approaches, two distinct issues are confounded—namely, the issue of what is innate is confounded with the issue of whether learning mechanisms are specific or domain general.

For the most part, nativist approaches typically posit *modules*, or specialized psychological abilities, that allow us to learn and acquire specific skills. This view, *domain specificity*, is a prominent theoretical position in cognitive science (especially modern cognitive development) that holds that many aspects of cognition are supported by specialized—presumably evolutionarily specified—learning devices often referred to as *modules*. Although the position is typically associated with nativism, it need not be. Domain specificity emerged as a theoretical alternative to empiricist theories that claimed all sorts of learning across domains could be driven by just a few, very general learning devices. One prominent example of a domain-general view includes Jean Piaget's theory of cognitive development (Piaget & Duckworth, 1970). Other domain-general views include behaviorism and the approaches taken by many modern connectionists (Elman et al., 1996). It is important to note, though, that empiricists largely remain open concerning the particulars of the relevant learning algorithms, and they are by no means restricted to the associationist mechanisms historically used by behaviorists.

Proponents of domain specificity argue that domain-general learning mechanisms are unable to overcome the epistemological problems facing learners. Like nativistic theories, domain-specific accounts draw support from the surprising competencies of infants, who are able to reason about things like numeracy, goal-directed behavior, and the physical properties of objects all in the first months of life. Domain-specific theories hold that these competencies are too sophisticated to have been learned via a domain-general process like associative learning, especially over such a short time, given the limitations of infant perceptual, attentional, memory, and motor abilities. The rationale behind domain-specific theories is that evolution equipped humans (and indeed most other species) with specific adaptations designed to overcome persistent problems to be encountered in the environment.

Yet, modularity and nativism are conceptually distinct, and one does not imply the other. For example, a system can become modular (i.e., look specific) through experience if the system's structure is sufficiently plastic. Karmiloff-Smith (1991) put forward a developmental theory that proposes that the brain may become modular through experiences such as social interactions or visual perception. According to this view, modules need not be innate. On the other hand, positing that infants possess complicated learning mechanisms also implies some innate structure. Thus, a learning mechanism that tracks probabilities and contingencies, that is biased to respond to certain features of the environment, or that is preferentially suited to learning some aspects of the environment or treats some aspects of the sensory world as special or privileged would be a system that is innate, but domain general. It is difficult to evaluate various theories in this regard because there is no common agreement about what *counts* as early emotion. Is it a reflex? A small discrete action? An extensive program for action? A bias toward or away from certain features in the environment? For example, an infant can display a *smile* at 1 week of age during REM sleep, at 1 month of age while being stroked, at 2 months of age during social interactions, and at 3 months of age when achieving mastery (such as pulling a string to make music) (Rosenstein & Oster, 1988). If one considers *happiness* to be inherent in the reflexes associated with the random neural activity of REM sleep, then the emotion does appear immediately after birth. However, if the construct of happiness refers to a more social/subjective definition, then the emotion does not appear until much later. In theories of emotion, there is a vagueness or uncertainty about these issues.

The crux of the problem is articulating what counts as early emotion and what drives the changes from these early behaviors into mature, differentiated emotions. Empiricist theories of emotion focus on how developmental change occurs, while underspecifying what gets development rolling. In contrast, nativist theories describe a rich set of emotion building blocks (basic emotions such as anger, happiness, etc.) and then underspecify how early learning and developmental change occurs. The oversimplified version of this view is that we are born with the neural circuitry that supports anger, and we come to have a more differentiated and sophisticated use and understanding of anger as those brain regions grow and form connections with other neural systems underlying processes such as inhibitory control, memory, and so on. This account presupposes that we are born with a system that supports anger and that there is an internal process of change associated with and (maybe) specific to the anger system. Conversely, in most empiricist views—those that are exclusively based upon notions of learning—the processes of developmental change are equally vague. Infants develop more sophisticated perceptual abilities and greater memory capacity, engage in increasingly complex emotional interactions, and somehow change from having periods of undifferentiated arousal or distress to culturally shared understanding and experiences of anger, sadness, joy, disgust, and so on. In sum, the neural mechanisms that humans use to learn about emotion may be no different than those we use to learn to roll sushi or play the piano.

CAN EMOTIONS BE LEARNED?

Because there is little data about the brain mechanisms underlying emotional behaviors, and because observations of children's emotional behaviors are inconclusive about nativism, the heart of this disagreement is the question of what is learnable and what kind of learning the human brain is capable of achieving successfully. The central issue is that the usual arguments advanced in the field of emotional development—that basic emotions are present at birth, that young infants are surprisingly and consistently emotionally competent, and that emotions are similar across cultures—provide an inadequate account of emotional development. For this reason, claims of learnability are central for resolving these issues.

Contemporary approaches to learning and development began with the study of language. Modern linguistics was strongly influenced by Chomsky's observation that language learners make grammatical generalizations that do not appear to be justified by the evidence available to children in the input they hear (Chomsky, 1965). Similar to Hume's argument about causality, Chomsky reasoned that children's generalizations are best explained by innate knowledge. Known as the argument from the *Poverty of the Stimulus*, this position has led to an enduring debate that is central to many of the key issues in cognitive science and human development more broadly. The Poverty of the Stimulus argument is based upon the limited nature of the input children are exposed to, and how much sensory information or evidence could support the complex skills that children master.

In the study of language, the conclusion of this argument is that children must have some innate biases. For example, they might innately favor *structure-dependent rules* (grammatical constructs that operate over phrases and clauses rather than simply over sequences of words). Knowledge about hierarchical structures in grammar could not be learned, according to this argument, because it is never taught, nor is the structure accessible through sensory input. Yet most children learn this quickly. As formulated, the argument based upon the Poverty of the Stimulus is an epistemological problem: The data children receive early in development is indeterminate. Given what we say to children, they would not be able to discern underlying grammatical rules unless they already had some predisposition to know those rules (for a recent example of this argument, see Lidz, Waxman, & Freedman, 2003). The linguistic stimuli that children receive are considered *poor* because there simply is not enough information in perceptual input for a child to learn the system. Simply put, *Poverty of the Stimulus* means that the output observed in the developing child is radically underdetermined by the input the child receives. This also appears to be the case with regard to the type of emotional stimuli that children receive.

There is an indefinite number of alternatives that could be logically consistent with the regularities found in the infant's emotional input. Consider that an infant might observe an adult cry when we are sad, upset, tired, frustrated, hurt, but also when we laugh hard or peel onions; we might cry when talking to others, when watching television, when on the telephone, or when remembering a past event, making the antecedents of the emotion unclear. There are, therefore, many ways in which the emotional learning environment is impoverished. Seyfarth and Cheney (2003a,b) argued that facial and vocal expressions actually have very low *informational value* regarding the internal state of the sender. Smiling faces are usually categorized as happy across cultures (Ekman, Friesen, & Ellsworth, 1972; Russell, 1994). Yet people can smile when they are not happy and can feel happy without smiling. Therefore, a smile does not provide a perfect predictor about the internal state of the sender. The emotion *code* that the developing child must master is further complicated because the nature of emotional signals fluctuates depending upon the persons with whom we are interacting. For example, different types of social interactions will result in laughs with different acoustic properties in the same individual (Devereux & Ginsburg, 2001).

Not surprisingly, although parents often believe that they are able to discern specificity in their own infant's emotional expressions, there is little empirical data to suggest that infants reliably produce emotional expressions with high informational value and referential specificity that map onto discrete emotion categories. One problem is that infants produce configurations of facial behaviors typically identified as *expressions* in situations in which the corresponding emotion is unlikely—by, for example, producing a *sad* facial expression when protesting a sour food (e.g., Camras, 1991; Camras, Lambrecht, & Michel, 1996; Matias & Cohn, 1993). Conversely, infants often fail to produce the predicted set of facial behaviors in situations in which the corresponding emotion is likely (Camras et al., 2002; Hiatt, Campos, & Emde, 1979). In general, it seems that infants have a range of facial behaviors that they use to express negative affect (Camras, Oster, Campos, & Bakeman, 2003) or intensity (Messinger, 2002). Similar findings are apparent in studies of infant crying (Bachorowski & Owren, 2002). Infant cries are very potent signals with salient acoustic properties that help caregivers judge an infant's level of distress and urgency of need, but there is little empirical evidence to support the commonly held notion that infants give distinctive cries unique to eliciting situations—such as when the infant is hungry, scared, tired, or in pain (Gustafson, Wood, & Green, 2000). Instead, what adults are usually able to discern is the intensity of the infant's affect rather than the meaning of the cry (Dinehart, Bolzani, Messinger, & Acosta, 2005). Taken together, this evidence suggests that facial movements and vocal signals do not necessarily display information about the sender's emotional state, even though people routinely perceive those behaviors as coordinated expressions.

Learning to decode emotional signals is also complicated by the fact that no single facial movement or vocal behavior can be associated with a single emotion category. Individual facial muscle movements are indeterminate: Wide eyes may be associated with fear or surprise, an open mouth with happiness, anger, fear, or surprise. Seyfarth and Cheney (2003a,b) refer to this problem as low *referential specificity*. For example, a smile can mean that one feels pleasure (Cacioppo, Berntson, Ernst, & Ito, 2000), embarrassed (Keltner, 1995), contrite (Schneider & Josephs, 1991), subordinate (LaFrance & Hecht, 2000), sexual interest (Mehu, Grammer, & Dunbar, 2007), or is attempting to appease others (Deacon, 1997). Of course, there may be distinctive types of smiles that signal distinctive mental states, but the consistency of such relationships remains to be demonstrated empirically. In general, many communicative behaviors in primates have multiple meanings, depending on their context (de Waal, 2003). At the same time, through this noise, the predictive information conveyed by smiling may well be sufficient to support early learning of emotion. In sum, expressions of emotion are extremely difficult to accurately identify with all contextual clues removed (Wagner, MacDonald, & Manstead, 1986). From a nativist perspective, this state of affairs suggests that emotion expressions would be unlearnable without some innate propensity to process emotions because infants are not able to access the contextual information necessary to interpret these expressions; therefore, an innate mechanism is necessary because most infants are clearly able to master emotion recognition in the absence of positive evidence or learning cues. However, from an empiricist perspective, infants may well be tracking the contextual cues that allow them to learn and interpret emotional signals.

One principle of a dynamic-system theory approach is that learning and development can build upon random occurrences (Camras & Witherton, 2005). Rather than assuming that the infant is learning when he or she sees someone express an emotion, this account holds that the infant begins to track how a random facial configuration such as a smile elicits certain responses from the environment that begin to reinforce the facial behavior. Such an approach can also integrate subjective feeling states. Adult engagement with the infant produces pleasurable feelings in the infant, not because the adult is smiling but simply because the engaged actions make the infant feel good. That feeling good becomes associated with a smile in the sensory environment—or that feeling bad becomes paired with the sound of crying—may emerge much later in learning. Here, the fact that the young infant may not differentiate self from other may facilitate emotion learning.

As adults, we tend to think of emotions as objective and consistent, but it is unlikely that emotions appear that way to an unbiased learner.

Why, for example, should we attend to faces as opposed to fingers when trying to discern another person's subjective feeling state? Why attend to vocal prosody and not hair color or gaze direction? The developing child also must learn to generalize something about the structure of emotions over vast individual differences in other people's manners of expression, facial characteristics, affective styles, as well as across males and females, adults and children, familiar and unfamiliar people. The scope of information that infants must learn to ignore is vast. Each voice has its own timbre, each face its own features and idiosyncrasies, each person a faster or slower or muted or intense style. So many aspects of biological motion are not emotional, yet children quickly learn that a sneer is an emotional communication, whereas a sneeze is not. Moreover, emotions can be present in the environment and have no immediate or salient impact upon the learner. A parent can express extreme anger or hostility toward a gate agent at an airport, but that may not have any direct effect on the interaction between the parent and his infant even moments later. In sum, a critical feature of emotion development—and a basic premise of the Poverty of the Stimulus argument—is that the correct set of patterns is no less simple to learn than other irrelevant or incorrect alternatives.

The general question is whether the data needed to decode emotional meaning are available to the learner. From a nativist perspective, the child could not arrive at the correct behavioral output through sensory-based learning. Since nearly all children do arrive at the correct output, from a nativist perspective this would not be possible without some form of domain-specific knowledge or bias to guide learning. Without some innate core knowledge, learners would have to rely on seemingly random sensory inputs to guide them through a vast array of information in the environment. The general point is that the ultimate goal in emotional development is mastery of signal–meaning pairings. Those signals may be subjective, motoric, or physiological. The deep problem is that no matter how much emotion a learner is exposed to, the various interoceptive and sensory signals cannot cohere and conform to a set of principles if he or she cannot categorize and remember them. That entails keeping track of a vast amount of information and disregarding other sources of information.

On the other hand, the soundness of the Poverty of Stimulus argument can be questioned. First, it is not clear that humans are exposed to features of the environment that are truly *unlearnable*. By analogy, in the study of language, one claim was that linguistic features such as infinite recursion could not be learned without innate grammar. While that may be true in theory, speakers cannot ever produce sentences with infinite recursive structures *in principle*. And even if speakers did produce such sentences, it is not clear that people are able to comprehend sentences with many levels of recursion. While some argue that such an example is best explained by restrictions on working memory rather than language abilities, it remains the case that the linguistic structures people actually produce may well be learnable; this is an empirical question.

Although the emotion data that young children receive have low informational value and referential specificity, is emotion—somehow—learnable through domain-general mechanisms? Do children actually receive enough evidence to learn the patterns of emotions through input alone? It is unclear whether the way to address this question requires a focus on the nature of the input or on the nature of the learning mechanisms available to the child. One way to approach the issue is to examine whether emotion learners do get certain kinds of negative evidence. Indeed, if children begin to form expectations or hypotheses about what might occur in the environment, and subsequent input either matches or does not match their expectations, then that is information that would support learning (Pullum, 1996). In other words, absence of an expectation or pattern is potentially useful negative evidence. Extant theories may also underestimate the probabilistic information in the environment. For example, nonoccurrence of a pairing is also important data for children. While we may smile or laugh for many reasons, we are extremely unlikely to laugh when we are hurt or disgusted. In this manner, there may well be plenty of cues for a savvy emotion learner to begin to use.

Another refutation of the Poverty of the Stimulus argument is the claim that human infants are more powerful learners than many theorists believed. For example, researchers using neural networks and other statistical methods have programmed computers to learn and extract hierarchical structures without negative feedback (see Bates & Elman, 1996; Solan, Ruppin, Horn, & Edelman, 2005). Such general learning mechanisms have been proposed for the ontogenesis of many cognitive abilities such as cross-modal matching, phonetic discrimination, and word segmentation (Kuhl, 1987; Kuhl & Meltzoff, 1982; Saffran, Aslin, & Newport, 1996).

Criticisms of the learning achievements of young infants in these sorts of paradigms are that, while sufficient to solve discrete or artificial problems in the laboratory, these mechanisms are not sufficient to learn complex behaviors in children's real environments. For example, most computational networks are designed to solve a small set of predefined problems (e.g., putting words in the past tense), whereas children have no way of directing their learning so narrowly. These are legitimate concerns that need to be tested. From a developmental perspective, the critical point is that the Poverty of the Stimulus argument is based upon the idea that certain things in the world are not learnable without innate knowledge and domain-specific learning mechanisms. Yet it now appears that more learnable information may be out there in the world than was previously recognized and human infants appear to be more powerful learners than we expected when such theories were developed.

APPLICATION OF THESE ISSUES TO CHILD HEALTH

Ultimately, emotional development is not about philosophical positions regarding the origin of knowledge. It is about what children face as they develop—not universals, evolution, or cross-cultural similarity. What we really need to understand, if we wish to translate basic science into interventions for maladaptive behaviors, is *how* change occurs. How does the individual child break into this social system of communication—what Papoušek and Papoušek have called our first language that enables parent–child communication (Papoušek, Jürgens, & Papoušek, 1992)? My own research has been based on the supposition that there is sufficient evidence in the input for a learner to discern the structure of human emotions and, further, that it is the nature and patterning of this early input that configures the neural circuitry involved in emotion processing. This account suggests that certain properties of the input, namely the salience and predictive validity of certain cues in the environment, are responsible for transitions in emotional development. There are two general points underlying this argument:

1. Early input to infants across families and cultures may be quite similar from the perspective of the developing brain.
2. All biological systems, including emotion, share a need to be responsive to environmental input in order to be adaptive and may therefore share some developmental properties.

Therefore, I consider emotional development as an emergent property resulting from complex learning.

One can consider three aspects of emotional development: the initial state of the infant, the input the infant receives, and the learning processes and cognitive operations that the infant applies to affective input. These components are not independent. For example, the informational content of the input defines the kinds of computations that might be performed and thus the representations that learning mechanisms might use. Therefore, in addition to investigating the initial state of the human infant with regard to emotional abilities, it is also necessary to address the input that learners receive and the learning that takes place early in development. My students and I have attempted to address questions about the emotional input children receive and processes of emotion learning by focusing on the development of children who receive atypical emotional input in the form of inadequate parental care. We attempt to do so in ways that allow developmental comparisons with rodents and nonhuman primates; each species allows exploration of a different level of analysis. Maltreatment of human children is notoriously difficult to define, measure, and investigate empirically. Nevertheless, this phenomenon has provided an important forum for investigating the role of environmental stress, individual differences, and developmental factors in the ontogenesis of social behavior.

Input and Learning: Clues from the Emotional Correlates of Child Maltreatment

Translational research holds tremendous promise for advancing scientific understanding about emotional development and leading to new ideas about clinical interventions. Importantly, many theoretical and practical issues arise in translating between typical and atypical processes and between species. In this section, I provide four examples, employing different kinds of methods, of the ways in which the study of atypical development can help illuminate the mechanisms underlying the learning of emotion and how basic research on emotion promotes better understanding of the ways in which interventions can be tailored to children at risk for emotion-related difficulties. These examples are not exhaustive, but they do highlight the interplay between conceptual issues, basic science, and prevention/intervention in developmental science.

Example 1: Emotional Input Received by Maltreated Children

Related to issues about the nature of the emotional input that children receive, recent work from my laboratory has begun to focus on the nature of maltreated children's input. Parents who physically abuse and/or neglect their children have been characterized by increased hostility, intrusive behaviors, aggressive outbursts, generally negative parenting techniques, and poorly expressed emotions (Bauer & Twentyman, 1985; Camras et al., 1988; Kavanagh, Youngblade, Reid, & Fagot, 1988; Lyons-Ruth & Block, 1996). However, there is little detailed empirical data on these children's expressive environments. We evaluated the facial and vocal expressions of a sample of physically abusive and nonabusive mothers and found that abusive mothers produced atypical and less recognizable expressions of anger (Shackman et al., 2008). For example, physically abusive mothers did not lower and contract their brows as most people do when angry, tended to smile less intensely, and produced lower levels of vocal emotions that lacked variation in pitch. Changes in pitch frequency are important sensory cues that make emotional prosody easier to discern (Bachorowski, 1999). These data suggest that physically abused children may be exposed to less prototypical emotional expressions in their early sensory environments.

The implication of the Shackman and colleagues (2008) study is that whatever kind of developmental mechanism that children use to learn about emotion is likely to be affected by degraded input. Typically, adults exaggerate sensory input to facilitate infant learning. For example, infant-directed speech (*motherese*), which is characterized by a higher fundamental frequency and greater pitch variations, is thought to facilitate infants' language learning (Thiessen, Hill, & Saffran, 2005). Similarly, adults often present infants with high-contrast toys and mobiles to stimulate visual development (Banks, 1980). If maltreated children are exposed to degraded emotional input—meaning that the quality of the signals they receive are less clear, inconsistent, and more difficult to understand—then it is not surprising that emotion learning could be compromised.

Example 2: Input-Related Effects on Sensory Processing and Domain Specificity/Generality

Given that maltreated children may encounter variations in their emotional input, it is possible that children's early experiences alter sensory thresholds for emotion. To explore this possibility as a learning mechanism for emotion, we examined how children categorize emotions. The phenomenon of *categorical perception* occurs when perceptual mechanisms enhance differences between categories at the expense of the ability to detect incremental changes in stimuli within a category (Harnad, 1987). This process is adaptive in that it allows an observer to efficiently assess changes between ecologically meaningful categories (to see that a traffic light has changed from green to yellow; to detect the difference between the pronunciation of a *v* and a *w*) at the cost of noticing subtle changes in a stimulus (such as shades of greens or yellows across individual stoplights, or how individual people pronounce their *v*s). Early demonstrations of categorical perception in the area of speech perception stressed the importance of specialized innate mechanisms (Eimas, Siqueland, Jusczyk, & Vigorito, 1971). However, later investigations revealed that perceptual capacities for speech, as well as other perceptual domains, are learned through experience (Werker & Tees, 1992). It appears that human infants enter the world with general perceptual learning mechanisms that allow them to conduct a preliminary analysis of their environments, but these mechanisms must become tuned to process specific aspects of the infants' environment (Aslin, Jusczyk, & Pisoni, 1998).

When shown facial expressions distributed along a continuum between emotions (e.g., happiness *to* sadness), adults perceive these stimuli as belonging to discrete emotion categories (e.g., happiness or sadness) (Young et al., 1997). And category boundaries for familiar and unfamiliar faces can be shifted in adults as a function of frequency of exposure to those faces (Beale & Kiel, 1995). This frequency effect suggests that experience may also play an important role in face perception. To determine if a *frequency* effect for emotions could also be detected, we examined physically abused children's categorical perception of emotional expressions and found that, while all the children we studied perceived emotions in terms of categories (e.g., sad, angry, happy, scared), physically abused children displayed a boundary shift for perceptual categories of anger relative to nonmaltreated children (Pollak & Kistler, 2002). Specifically, physically abused children displayed equivalent category boundaries to nonabused children when discriminating continua of happiness blended into fear and sadness. However, these same children evinced different category boundaries when discriminating angry faces blended into either fear or sadness. These data suggest an effect of learning on the formation of perceptual representations of emotion and, given that categorical perception mechanisms appear to operate similarly across domains and various species (including humans, birds, and chinchillas), that this process may reflect a domain-general learning mechanism subserving emotional development.

Example 3: Input-Driven Cognitive Mechanisms

Children's deployment and control of attention represents another way in which to examine the role of learning in emotional development. The adaptive nature of involuntary attention allocation lies in its ability to quickly alert an organism to a possible danger or other significant event (Sussman, Winkler, & Schröger, 2003). Voluntary allocation of attention toward or away from certain environmental cues is a mechanism that allows children to effectively regulate emotional states (Posner & Rothbart, 1998; Rothbart, Ellis, Rueda, & Posner, 2003). Indeed, a central function of emotion is that it represents a mechanism for alerting an organism to potentially significant events. The emotional salience of the environmental events that capture attentional systems emerges through an organism's learning history (Berti & Schröger, 2003). To examine the ways in which early emotional experience affects voluntary and involuntary attention, we manipulated the task relevance of conflicting affective cues and used event-related potentials (ERPs) to measure physically abused children's cognitive processing. ERPs, which are scalp-derived changes in brain activity over time, are a noninvasive method that is well-suited for studying the neural mechanisms underlying emotion processing in clinical populations of children. Specifically, ERPs allow for the precise temporal measurement of earlier aspects of cognitive processing, which cannot be revealed through techniques such as functional magnetic resonance imaging (fMRI). Of relevance to issues of emotional learning are two specific components of the ERP. One is the P3b, which reflects processes involved in attentional resource allocation, difficulty of stimulus evaluation, the updating of environmental context in working memory, and emotional salience (Keil et al., 2002; Miltner et al., 2005; for discussion, see Pollak & Tolley-Schell, 2004). The second is the N2, associated with cognitive inhibition and regulatory processes (Lamm, Zelazo, & Lewis, 2006; Yeung & Cohen, 2006). In earlier studies (Pollak et al., 1997, 2001) we demonstrated that physically abused children's attention was to facial displays of anger, but not other emotions.

In a more recent study, we extended this research by presenting children with congruent and incongruent facial and vocal emotion expressions while directing their attention toward either the visual or auditory modality. It was important, here, to address questions not only of attention to emotion, but also to examine children's emotion processing more broadly by including vocal expressions of emotion in addition to face processing. Vocal expressions of emotions are particularly important from a developmental perspective in that auditory signals can capture attention from someone who is not already visually attending to the expresser, as is often the case in the communications between infants and toddlers and their caretakers. Despite the salience of auditory cues, Fernald (1993) argued that little attention has been directed toward understanding the role of vocal expressions in emotion perception. Because our previous studies of emotion processing had employed standardized facial stimuli, we also designed this study to use stimuli that depicted children's own parents, with the hypothesis that personalized stimuli might be especially useful for excavating perceptual learning processes.

In general, we found that physically abused children (a) exhibited increased voluntary attention toward both facial and vocal anger cues, (b) were involuntarily drawn to vocal anger cues, and (c) were especially responsive to facial signals of anger from their own parent (Shackman, Shackman, & Pollak, 2007). Physically abused children showed enhanced P3b amplitude when directing their attention to their own mother's facial anger. The groups of abused and control children did not differ when attending to anger posed by unfamiliar adults, or when attending to happy and sad facial expressions posed by either their parent or another adult. Additionally, abused children displayed increased N2 amplitudes when presented with angry distracter cues, suggesting they expended greater effort inhibiting the involuntary processing of task-irrelevant anger. These ERP data suggest that abused children exert more cognitive effort both to engage their attention toward salient anger cues and also to withhold further processing of irrelevant but salient affective cues in the environment, compared to control children.

Example 4: Input-Driven Physiological Mechanisms

In one of our earliest studies, we found that physically abused children perceived angry faces as highly salient relative to other emotions (Pollak et al., 2000). A significant aspect of this study was that we were able to contrast children with different types of maltreatment experience. Physically abused children had experienced *abuse by commission* in that a parent directly injured them. In contrast, neglected children experienced *abuse by omission*—lack of care and responsiveness from parents. Neglected children, who purportedly received less parental support and experience in learning about communicative signals, had difficulty differentiating facial expressions of emotion. Rather than showing global deficits in performance, physically abused children performed well, especially when differentiating angry facial expressions (Pollak et al., 2000). These data suggest that specific kinds of emotional experiences, rather than simply the presence of stress or maltreatment, differentially affect children's emotional functioning. Subsequent studies revealed that institutionally neglected children not only had difficulties differentiating between, and responding to, expressions of emotion but also showed developmentally unusual patterns of formulating selective attachments to caregivers (Wismer Fries & Pollak, 2004).

In a typical social environment, caregivers learn how to recognize and respond to their infants' needs, thereby creating predictable contingencies in the environment; these regularities, in turn, make the infants' environments conducive to further learning (Bigelow & DeCoste, 2003). Another way to address issues of learning in emotional development is to examine the extent to which the neurobiological systems that regulate behaviors such as attachment are dependent upon the social experiences afforded to most infants. With this goal, we studied a sample of children who did not receive the kind of emotionally responsive caregiving typically received by human infants. These children were reared in institutionalized (orphanage) settings, where a prominent lack of emotional and physical contact from caregivers is a consistent adverse feature of the environment.

The specific systems that we explored were the oxytocin (OT) and arginine vasopressin (AVP) neurohypophyseal peptide systems. Research with nonhuman animals suggested that OT and AVP are an integral part of mammalian emotional circuitry (Carter, 1998; Fleming & Corter, 1995; Uvnas-Moberg, 1998; Winslow, Hastings, Carter, Harbaugh, & Insel, 1993). Specifically, these neuropeptides are associated with the emergence of social bonding, parental care, stress regulation, social communication, and emotional reactivity (Insel, 1992; Young & Wang, 2004). OT receptors are part of the neural system of reward circuitry that includes the nucleus accumbens; a critical feature of this system for infant development is that it likely confers a sense of security and protection that makes social interactions rewarding. A growing body of research with rodents suggested that early social experience, through changes in corticotropin-releasing-hormone (CRH), may alter OT and AVP receptor binding (Bester-Meredith & Marler, 2003; Champagne, Diorio, Sharma, & Meaney, 2001). Therefore, we reasoned that early social experience would influence the feedback loops involving social reward circuitry, with developmental implications for stress reactivity and behavioral regulation as the infant matures. Indeed, higher levels of OT are associated with decreases in stress (Lovic & Fleming, 2004).

We found that children who had experienced early institutional neglect had lower overall levels of AVP than family-reared children

(Wismer Fries & Pollak, 2004). These results suggest that social deprivation may inhibit the development of the AVP system. Functionally, central AVP appears to be critical for recognizing familiar individuals, a key component of forming social bonds (Wang & Aragona, 2004). Because emotions are inherently regulatory processes, we evaluated how these neuropeptide systems responded to dynamic social interactions. To do so, we examined hormone levels approximately 20 minutes after children interacted with their mothers. OT levels for family-reared children increased following physical contact with their mothers. Children who experienced early institutional neglect did not show this response following physical contact with their mothers (Wismer Fries & Pollak, 2004). To what extent are the neurobiological mechanisms underlying human emotional behavior dependent upon the social experiences afforded to most infants by their caregivers? These results suggest that a failure to receive species-typical care disrupts the normal development of the OT and AVP systems in young children. Perturbations in this system may interfere with the calming and comforting effects that typically emerge between young children and familiar adults who provide care and protection.

Caveats About Interpreting Studies of Maltreated Children

Important basic science issues in emotion are drawn from studies of nonhuman animals in that invasive methods and experimental manipulations that are not possible or appropriate with humans can be used. At the same time, generalizations about the biological processes underlying emotional behaviors across species require caution for a number of reasons (for full discussion of these issues, see Sanchez & Pollak, in press). Animal models do not always mimic human emotional disorders; brain development, structure, and function are not identical across species; there are chromosomal differences between species; and the actual behaviors exhibited by parents and the way they are received and experienced by offspring are not identical across species. Cross-species comparisons are justified, however, because there may well be common denominators in the roots of emotional functioning across species (Gunnar & Fisher, 2006). One of these may be the role of caregiving, with the effects of poor or inadequate parental nurturance providing critical clues about the mechanisms through which sensory experiences influence emotional development. Indeed, the developmental outcomes of infant maltreatment among nonhuman primates are strikingly similar to those reported in maltreated children (Sanchez et al., 2007).

As discussed earlier in this chapter, most children may develop within relatively typical caregiving environments, making it difficult to fully evaluate the role of early experiences in the configuration of emotion systems. For this reason, the study of maltreated children may be particularly informative. At the same time, studies of clinical or atypical populations cannot harness the staple tool of experimental psychology: random assignment. One caution about using a phenomenon such as child abuse as a way to understand learning mechanisms underlying emotion is the assumption that abuse is the cause, rather than the effect or correlate, of subsequent atypical behavior. It is theoretically possible that heritable factors that co-occur with maltreatment, rather than the experience of being maltreated, are responsible for the behavioral difficulties observed in children. It is also theoretically possible that some individuals carry heritable traits that influence emotional development in ways that increase the likelihood of experiencing maltreatment. In these cases, the study of abused children would be much less informative with regard to understanding the mechanisms of emotional development. Yet converging behavioral genetic data from monkeys and humans highlight the role of postnatal sensory experience in this regard. As in humans, physical abuse in rhesus monkeys has a high prevalence in some family lineages, suggesting intergenerational transmission. However, evidence from rhesus cross-fostering studies suggests that behavioral problems observed in monkeys are due to the postnatal experience of maltreatment rather than genetic heritability (Maestripieri, 2005). Behavioral and molecular genetic analyses also support the view that the experience of abuse has a causal role in the formation of emotional behaviors (Kim-Cohen, 2007). Thus, the phenomenon of child maltreatment is well poised to figure prominently in considerations of the relative contributions of learning in emotional development. In particular, studies of maltreated children (and nonhuman primates) may help excavate the neural learning mechanisms through which sensory experiences influence emotions.

For some scientists, a developmental mechanism might be a behavioral, cognitive, or computational explanation for behavioral change. Increasingly, psychologists are seeking potential neural systems that might account for emotional behaviors. No one level of analysis or type of approach appears to confer an epistemological advantage here, as emotional development occurs at neurophysiological, behavioral, and subjective levels. Still, it is useful to consider the extent to which hypothesized accounts of developmental change are at least biologically plausible. As an example, our findings suggesting perceptual processing differences among abused children are consistent with studies suggesting experiential malleability in the neural circuitry underlying modification of prefrontal neurons (Freedman, Maximilian, & Poggio, 2001). The prefrontal cortex is certainly not the only brain area involved in cognitive tasks as complex as categorization of emotion. Other structures are likely to be relevant to children's emotional functioning such as temporal lobe structures and inferior temporal cortex, both of which may underlie the storage of memories and associations relevant to emotion perception, as well as attentional effects on the fusiform gyrus, implicated in development of face expertise networks (Tomita, Ohbayashi, Nakahara, Hasegawa, & Miyashita, 1999; Wallis, Anderson, & Miller, 2001).

Among the most clinically relevant and consistent findings for abused and neglected children are high levels of anxiety and fear. Studies of isolate-reared monkeys have revealed decreased white matter in parietal and prefrontal cortices as well as alterations in the development of hormone receptors that underlie fearful and anxious behaviors (Sanchez et al., 2007). We (Pollak, Bechner, Vardi, & Curtin, 2005) examined attention regulation in physically abused preschoolers who presented with interpersonal hostility—a situation that predicts abuse in these children's home environments. Autonomic measures such as heart rate and skin conductance were measured in abused and nonabused children while they overheard two unfamiliar adults engage in an argument. The abused children maintained a state of anticipatory monitoring of the environment, from the time the actors began expressing anger throughout the entire experiment—even after the actors had reconciled. This response was quite distinct from that of the nonmaltreated children in the study; the nonmaltreated children showed initial arousal to the expression of anger but were better able to regulate their responses once they determined that it was not personally relevant to them. This type of response to emotional cues in their environments is likely to guide children's social behaviors in ways that are maladaptive. Findings such as these are consistent with a growing body of evidence that indicates that somatic states related to emotion are involved in cognition and learning (Bechara, Tranel, Damasio, & Damasio, 1996; Damasio, 1999; Lo & Repin, 2002). For example, individuals who show stronger somatic marking (larger skin conductance responses; SCRs) also show stronger learning performance (Carter & Pasqualini, 2004). Thus, autonomic arousal in response to threat may initially serve to bias attention toward such salient emotion cues.

Another system potentially linking children's early experiences with subsequent behavior is the limbic hypothalamic pituitary adrenal axis (L-HPA). The L-HPA axis, as well as other afferent and efferent pathways of threat detection and response systems that extend into the prefrontal cortex, is particularly open to modification by experience during early life. The L-HPA system mediates neuroendocrine responses to stress, resulting in the release of steroid hormones from the adrenal gland. These hormones, glucocorticoids, affect a broad array of problems experienced by abused children, including energy mobilization, immune responses, arousal, and cognition (Hart, Gunnar, & Cicchetti, 1995). In a recent study, we found that the degree or severity of neglect experienced by children was associated with long-term regulatory problems of the stress-responsive system (Wismer Fries, Shirtcliff, & Pollak, 2008). Not surprisingly, alterations in pituitary and adrenal function have been associated with illnesses common among previously abused individuals, including depression, anxiety, Posttraumatic Stress Disorder (PTSD), fibromyalgia, hypertension, and immune system suppression (Altemus, Cloitre, & Dhabhar Firdaus, 2003).

Our ERP studies point to some neural mechanisms underlying emotional development. For example, the prefrontally mediated, anterior attentional system appears to track salient properties of target stimuli (Derryberry & Reed, 2001; González, Fuentes, Carranza, & Estévez, 2001; Posner & DiGirolamo, 1998). This may be one of the brain systems affected by maltreatment. Over time, this system may help abused children to learn about the predictive value of anger in a maltreating environment. Yet the enhanced attentional processes that are adaptive in an abusive context may lead to maladaptive behaviors in more normative situations, with aberrant processing of threat cues increasing the child's risk for anxiety. Not surprisingly, the degree of children's attentional differences on our ERP tasks correlates with both the magnitude of abuse the child endured and the child's degree of anxiety symptoms (Shackman et al., 2007). For these reasons, we speculate that the inability to flexibly regulate attention in the presence of threat cues may represent a mechanism by which plasticity in learning confers risk for maladaptation.

FUTURE POSSIBILITIES FOR TRANSLATIONAL APPROACHES

Translational research efforts aimed at understanding the emergence of emotion can meaningfully inform child-oriented interventions. Such research might be aimed at specifying the nature of the emotional input children receive and the mechanisms children use to learn from and respond to their emotional experiences. This type of research would uncover the neurobiological, sensory, and cognitive effects of early experience and thereby help to focus research attention on the precise nature of the problems experienced by children at risk for mental health problems. To illustrate, consider one of the common concerns that mental health professionals frequently observe in children who have endured child abuse and/or neglect: subjective feelings of anxiety, fear, or threat. These feeling states may lead children to any number of developmental pathways. Heightened fear might precipitate mood-regulation problems such as anxiety or depression, somatic and general problems with physical health including immune deficiencies, aggressive responses to perceived feelings of threat or insecurity, or perhaps subclinical feelings of unhappiness that detract from a sense of well-being.

One hypothesized pathway through which children's early experiences might impact sensory thresholds for responding to emotional stimuli may be altered perceptual or attentional processing of emotion (e.g., hypersensitivity to threat-related cues, hyposensitivity to positive or security-related cues). Another pathway might involve the L-HPA system, with its regulatory peptide (corticotropin-releasing hormone, CRH) and cortisol influencing the reciprocal regulatory relationship between the frontal cortex and the amygdala. A third potential pathway could involve functioning of the oxytocin system, which could influence children's developing abilities to feel secure, comforted, and protected. Oxytocin receptors appear to be heavily located in the nucleus accumbens and tightly linked to dopamine systems. These links to reward circuitry suggest that the pleasure and comfort provided by others may be learned or acquired through experience. Thus, atypical development of this reward circuitry may impair the capacity to bind pleasurable human contact with positive emotion states. In addition, oxytocin may help constrain stress responsivity. The more comforted and secure we feel, the harder it may be to become stressed; whereas if we feel unprotected or vulnerable, it is likely easy to trigger a stress response. In this manner, low OT may help account for both the prevalence of attachment-related difficulties as well as frequent observations of cortisol dysregulation and fearful behaviors in abused children.

The general point is that similar emotional outcomes observed in children may be the result of many different kinds of processes, each of which would warrant distinct methods of intervention. Future research that advanced our understanding of the specific primary mechanisms affected in individual children could enlighten development of biologically inspired intervention efforts tailored to address specific processes. Some children might benefit from interventions that emphasize a psychoeducational component wherein children receive explicit instruction in learning to read emotional cues, whereas other children might receive experiences that recalibrate perceptual systems of emotional expressions, and still other children might be taught how to test hypotheses about their interpretation of other people's affect. Other kinds of interventions might focus less on perception of sensory input but promote development of regulatory strategies (see Rothbart and colleagues, this volume). Because perceived stress can influence prefrontal functioning through catecholamine-based and CRH-mediated processes, techniques that help children inhibit medial prefrontal activation could help address fearful behaviors. Development of novel interventions could also focus on oxytocin as outcome measures—for example, by using the healthy functioning of this system to determine response to treatment, or by using basic science data about the functioning of this system to consider the types of social and emotional experiences that could help trigger OT release and be integrated into treatment design. These examples are certainly not meant to be exhaustive. Rather, my intent is merely to speculate about the myriad ways in which advances in basic translational developmental science could spur innovative research into new treatments and how demonstration of effective ways to treat children with emotion-related difficulties could likewise inform our understanding of the basic mechanisms of emotion. Such work is needed to build bridges between basic data that can transform diagnosis, treatment, and the domain of preventive/intervention for children.

CONCLUSION

Understanding the processes through which early social experience affects child development increases the likelihood of developing effective prevention and intervention programs. Studying children who have experienced atypical emotion-learning environments, such as maltreated children, also yields valuable knowledge about fundamental issues in psychological science. These include a focus on the neural circuitry and neurobiological regulation of emotion and their subsequent implications for behavior, as well as understanding adaptations and sequelae of chronic social stress exposure on affective neural circuits—especially during periods of rapid neurobiological change when the brain may be particularly sensitive to contextual or environmental influences. Because existing data have not rendered it possible to reach firm conclusions about whether emotion is innate, we have examined the development of emotion among children whose environments have differed in important ways from a species-typical caregiving environment. The general principle behind these studies is that examining the ways in which the aberrant environments influence biobehavioral development may highlight the nature of the learning mechanisms underlying emotion. Studying this question across species and across typically and atypically developing populations of children may highlight learning mechanisms that may not be obvious when emotional development is unfettered. Ongoing research in this area is focusing on defining and specifying ways in which the environment creates long-term effects on brain and behavior, including potential corrective experiences that might foster recovery of competencies and promote health.

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