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Linda A. Camras
Department of Psychology, DePaul University, USA

Abstract

In recent decades, considerable progress has been made in our understanding of emotional development. Yet no single current theory can fully encompass all of the empirical findings. Herein I propose that aspects of several theoretical approaches can be incorporated into a novel view that is informed by the dynamical systems perspective.

Keywords
dynamical systems, emotional development, facial expressions

Reflecting scholars' increasing recognition of the importance of human emotions, several theories of infants' and children's affective development have been proposed in recent decades (see Camras & Fatani, 2008, for review). Among these theories, three may be identified as representing influential yet fundamentally different approaches to conceptualizing both the organization and development of emotion: Izard's differential emotions theory (DET; Izard, 1991; Izard & Malatesta, 1987), Campos' functionalist perspective (Barrett & Campos, 1987), and the differentiation viewpoint originally advocated by Bridges (1932) and later adapted by Sroufe (1996). Each of these approaches has made important—yet somewhat different—contributions to our thinking about and understanding of emotional development. In this article, I present a theoretical viewpoint that incorporates aspects of all three approaches and is itself informed by the dynamical systems perspective (for earlier incarnations, see Camras, 1991, 1992, 2000; Camras & Shutter, 2010). It begins with a focus on facial expressions but subsequently is extended to more fully encompass emotional development. For expository purposes, I will refer to this as the differentiation and dynamical integration (DDI) perspective. However, beyond presenting this specific proposal, I will argue that the dynamical systems perspective itself can provide a framework within which future scholars may develop an even more fully articulated theory of emotional development that can incorporate a broad range of empirical findings and observations as well as pave the way for future research.

Three Contemporary Views of Emotional Development

To provide a context for subsequent discussion, I begin with a brief exposition of the three developmental theories indicated above. According to DET (Izard, 1991; Izard & Malatesta, 1987), discrete emotions (such as joy, anger, sadness, and fear) are hard-wired systems that emerge during the course of development according to a maturational timetable. Each emotion has three constituent components: neural, expressive, and experiential. Among the modes of expressive responding, facial expression has been considered of primary importance and the detailed MAX and AFFEX systems for coding and interpreting infant emotional facial expressions have been developed (Izard, 1995; Izard, Dougherty, & Hembree, 1983). The hard-wired linking between facial expression and other emotion constituents is thought to be most clearly evidenced during the first year of life, before socialization influences can override the automatic output of expressive responses during an emotion episode.

Corresponding author: Linda A. Camras, DePaul University, Department of Psychology, 2219 N. Kenmore Ave., Chicago, IL 60614, USA. *Email*: lcamras@depaul.edu

In contrast to DET, Campos' functionalist perspective (Barrett & Campos, 1987) views emotion as a relational process through which an individual attempts to establish, change, or maintain some significant aspect of his or her relationship to the environment. Importantly, there are no specific hard-wired responses that are invariably produced during an emotion episode at any point during development. Instead, responses may vary across episodes of the same emotion according to their functionality (i.e., their implicitly or explicitly perceived appropriateness for achieving the emotion-related goal in a particular situation). With respect to expressive responses, the functionalist perspective thus holds that emotional facial expressions are social signals that are produced only when they might achieve emotion-related communicative goals.

Like the functionalist perspective, differentiation-oriented views of emotions and emotional development provide an alternative to DET's focus on the emergence of innate invariantly structured discrete emotions. According to Sroufe (1996), adult emotions (e.g., anger, fear, joy) have developmental precursors (i.e., frustration, wariness, and pleasure) that are not acknowledged to be fully fledged discrete emotions because their cognitive underpinnings are immature. Of particular relevance to this article, Sroufe (like Campos) also asserts that expressive responses are not linked to emotions in an invariant manner even during infancy.

Prior to Sroufe, a somewhat different version of differentiation theory dominated the literature on emotional development for several decades. Consistent with Heinz Werner's general orthogenetic principle of development (Werner, 1948, 1957), Katherine Bridges published a highly influential monograph that described infant emotions as originating in a global state of diffuse excitement. This initial broad-spectrum emotional state differentiated into delight and distress and then to more discrete emotions such as fear, anger, elation, and affection. Differentiation was manifested in the development of more distinctive responses to different emotion elicitors. Although Bridges did not specifically address the relationship between facial expression and other aspects of emotion, the implication of her position is that expressive signals would differentiate as do other emotion-related responses. In addition, during the course of development, expressions would be integrated with other (progressively differentiated) behaviors to form more coherent discrete emotion systems.

Limitations of the Theories

The position to be advocated in this article (i.e., the DDI perspective) was developed primarily in response to problems identified during the author's attempt to confirm differential emotions theory's (DET's) proposals regarding the relationship between infant facial expression and infant emotion. For this purpose, the focus was on a set of "prototypic" infant emotional facial expressions as described within the MAX and AFFEX coding systems associated with DET. In the course of that effort, several phenomena were identified that could not be easily reconciled with the claims of DET. Some of these phenomena also were difficult to accommodate within other theoretical perspectives as well, eventually leading to the search for an alternative framework.

Five problematic phenomena that were identified will be briefly described. First, some emotional facial expressions were observed in situational contexts during which the emotion was unlikely to be present. For example, MAX-specified prototypic surprise expressions often were produced by 5- to 7-month-old infants as they brought familiar objects into their mouths (Camras, Lambrecht, & Michel, 1996). Second, predicted emotional expressions failed to be produced in contexts during which an emotion was widely acknowledged to occur. For example, 10- to 12-month-old infants very rarely produced a MAX-specified fear expression during the visual cliff procedure, although their other behaviors indicated that they indeed experience fear (Hiatt, Campos, & Emde, 1979). Instead, the infants more often produced MAX-specified expressions of physical distress/pain or anger. Third, observed eliciting contexts for several different discrete negative emotional expressions did not seem to differ. For example, in a naturalistic observational study of a single infant, Camras (1992) found a virtually complete overlap in the situational contexts during which MAX-specified expressions of physical distress/pain, anger, and sadness were produced. A review of the empirical literature revealed similar findings in other studies (Camras, Malatesta, & Izard, 1991), as has a more recent investigation of 11-month-old infants' expressions during anger and fear situations (Camras et al., 2007). These observations (along with findings from rater judgment studies of infant facial expressions and body behavior; reviewed in Camras & Shutter, 2010) suggest that the MAX-specified expressions for "pain," "anger," and "fear" actually represent more generalized states of negative affect (often termed "distress") in young infants. Fourth, systematic temporal sequencing of physical distress/pain, anger, and sadness expressions was (informally) observed during bouts of infant crying (Camras, 1992). This suggested that the three expressions may be related to factors other than the presence of a discrete emotion (e.g., respiration cycles during crying). Fifth, more than a single expression has been described for some emotions without providing a theoretical rationale for such variability. For example, according to the MAX-coding system (Izard, 1995), interest expressions may involve either raised brows or contracted brows. However, no explanation for such variability is provided. These discoveries led to the search for an alternative theoretical approach that could incorporate findings with respect to infant facial expressions better than could DET.

The Dynamical Systems Approach (DSA)

The dynamical systems perspective is a content-free approach to explaining the organization of complex systems. The approach was initially developed to account for the organization of physical and biological systems (see Haken, 1983) but also has been utilized within the social sciences (e.g., Vallacher & Nowak, 1994). DSA was first introduced to developmental scientists by Esther Thelen, Alan Fogel and their colleagues (Thelen, 1985a; Thelen, Kelso, & Fogel, 1987; Thelen & Smith, 1994) who utilized a "synergetics" version of DSA to explain infant motor development. Given that facial expressions are a form of motor action, DSA concepts and principles might be particularly appropriate for explaining the organization and development of emotional facial expressions (Fogel, 1985; Fogel & Thelen, 1987; Thelen, 1985b).

With respect to emotional facial expression, a particular strength of DSA is that it offers concepts and principles that can account for some of the expressive phenomena that remain unexplained within the theoretical frameworks reviewed above. One such important concept is the coordinative motor structure (CMS; Fogel, 1985; Kelso, 1995; Kugler, Kelso, & Turvey, 1980). Coordinative motor structures are sets of muscle actions that are synergistically related to each other such that the action of one muscle will recruit (or sometimes inhibit) the action of other muscles that are part of the system. Coordinative motor structures were introduced by DSA-oriented movement scientists to explain what is sometimes known as "Bernstein's Problem" (Bernstein, 1967). Bernstein's Problem starts with the observation that functionally equivalent motor actions are never completely equivalent topographically. Actions are like snowflakes; for example, no two instances of "reaching" are ever exactly alike. This is because contextual demands on an action are never identical; for example, the cup you are reaching for twice is never situated exactly the same with respect to your body. Thus your motor actions must be somewhat different in order to achieve the same action goal in two separate acts of reaching.

How can one explain the control of such variability within sets of functionally equivalent actions? Two possibilities may be considered (Fogel & Thelen, 1987; Kelso, 1981; Kugler et al., 1980; Oyama, 1989; Thelen, 1989). The first possibility involves positing complete control by some sort of central executive program or agent that sends "commands" to the motor output system. This agent monitors the details of the environment in order to fine-tune commands to each individual muscle that is activated. However, many movement scientists have deemed this solution to be overly burdensome, placing too much demand on the central command system. A second possible solution posits the distribution of control between top-down (central) and bottom-up (lower level) influences. These lower level influences involve the operation of coordinative motor structures (Kelso, 1995; Kugler et al., 1980). Thus, during an episode of walking over uneven ground, when one muscle element of the structure is activated (e.g., via pressure from a pebble on the ground), then other synergistically related muscle actions are recruited to compensate and prevent loss of balance and maintain coordination. Coordinative motor structures are considered to be a type of dynamical systems "attractor," a concept to be explained further below.

Facial Expressions as Coordinative Motor Structures

The concept of coordinative motor structures has proven to be particularly useful in explicating two of the problematic facial-expression phenomena outlined earlier: (a) the existence of several alternative prototypic expressions for certain emotions, and (b) the occurrence of prototypic "emotional" facial expressions in nonemotion situations. Two studies illustrate how the concept of coordinative motor structures can explain these phenomena.

In one study, Michel, Camras, and Sullivan (1992) demonstrated that 5- to 7-month-old infants systematically differed in their production of two versions of the interest expression depending upon their head position and gaze direction. Infants were presented with objects (small toys such as a rattle) from either above or below their horizontal line of sight. Infants produced the raised-brow version of the interest expression significantly more often when the object was presented from above and therefore the infant raised her chin and looked upward at the object. There also was a nonsignificant tendency for infants to produce the contracted-brow version of the interest expression when the object was presented from below. Based on these findings, the authors proposed that gaze lifting, chin lifting, and brow raising constitute a coordinative motor structure, that is, a set of synergistically-related muscle movements. When one component of the structure is activated (e.g., gaze lifting), then the other components are recruited and also tend to be produced.

In a second study, Camras et al. (1996) showed that infants also tend to raise their brows as they open their mouths, thus producing a facial expression that would be coded as "surprise" using the DET-based MAX coding system. Infants were again presented with small toys (this time at eye level) and were allowed to grasp and bring these to their mouths. Results showed that infants tended to produce raised brows more often when they opened their mouths to incorporate the object than in control episodes that did not involve mouth opening. These "surprise" expressions were not accompanied by any nonfacial indications of surprise, and the infants' readiness to mouth the objects suggested that the toys were perceived as being ordinary. The findings were interpreted as indicating that mouth opening and brow raising also constitute a coordinative motor structure that may be activated when one component (mouth opening) is generated in circumstances that do not necessarily involve the emotion of surprise.

Some Further Dynamical Systems Constructs and their Relevance to Facial Expression

As indicated earlier, coordinative motor structures are considered to be a type of dynamical systems "attractor." Beyond the two phenomena discussed above, this dynamical systems concept (as well as other dynamical systems principles) could potentially be used to explain other problematic observations regarding emotional facial expressions, and also could provide the framework for a broader theory of emotional development.

Complementing the observations related to Bernstein's Problem, DS-oriented movement scientists (Kelso, 1995; Turvey, 1990) also have emphasized that complex systems often involve numerous components (e.g., muscles in the body) that theoretically could be combined in an infinite number of ways. Yet systems generally assume a limited number of preferred combinations or patterns (e.g., crawling, walking and running). These are termed "attractors" (Abraham & Shaw, 1992). Attractors are relatively stable yet may involve a certain degree of variability (e.g., minor variations in stepping movements during walking). Variability in how system components are combined depends on contextual factors (e.g., unevenness of the walking surface, as suggested above) and also on initial conditions (e.g., position of the foot prior to initiating a stepping movement). To emphasize the importance of these bottom-up influences, attractors often are described as being "self-organized" (e.g., Fogel et al., 1992; Kelso, 1995; Thelen, 1989).

Two other dynamical systems concepts are particularly relevant to both facial expressions produced in real time and to the developmental considerations that will be addressed below: control parameters and phase shifts (Kelso, 1995; Schoner & Kelso, 1988; Thelen & Smith, 1994, 2006). A phase shift is the qualitative change from one organizational pattern (i.e., attractor state) to another (e.g., from walking to running). DSA-oriented scientists note that such changes often occur when there is a quantitative change in one parameter of the system. For example, when a person's speed of movement increases beyond a certain point, he will tend to shift from walking to running. Such changes are nonlinear; a person "breaks into a run." The parameter whose change results in a phase shift when it achieves a critical threshold value is termed a "control parameter." Control parameters do not "cause" a phase shift in the traditional sense of determining the form of the ensuing organizational pattern. Instead, they act by destabilizing the current pattern, thus producing a circumstance in which the system must reorganize itself to achieve a new state of stability.

Control parameters for facial expressions potentially could provide an explanation for problematic expressive phenomena that are poorly explained within DET. To illustrate, as will be recalled, one such phenomenon is the occurrence of prototypic "emotional" expressions in unexpected situations (e.g., "surprise" expressions while mouthing objects). According to DET, such occurrences are interpreted as indicating that the infant must indeed be experiencing the corresponding emotion despite the implausibility of such an emotion experience from an adult perspective. In contrast, according to the DSA, such unexpected occurrences of "emotional" expressions may be due to the operation of nonemotion factors (e.g., head, gaze, or mouth movements) that can serve as control variables with respect to the production of a facial expression. A second problematic phenomenon is the absence of an emotional expression when the emotion is likely to be present. Proponents of DET explain this by arguing that when emotion is weak, the facial actions also may be too weak to be manifested in visible facial behavior. However, this explanation lacks plausibility when introduced to explain an exemplar situation in which other types of facial expressions are produced (e.g., physical distress/pain expressions rather than fear expressions shown by babies on the visual cliff). According to the DSA, absence of an emotional expression in an emotion episode is not problematic; emotions may be considered to be variable ("chaotic") attractors, and individual components (such as facial expressions) may or may not be produced depending on the initial state of the system (e.g., where the person is looking) and on contextual control parameters that may be specific to the expression itself. Although such control parameters for prototypic fear expressions have yet to be identified, previous successes in pinpointing such parameters for other expressions (e.g., "surprise" and "interest" expressions as described above) suggest that future efforts in this direction would prove fruitful. In summary, DSA can accommodate these (and other) anomalies of infant facial expression better than DET because it allows for the possibility of nonemotion contextual influences.

Dynamical Systems and Development

According to the dynamical systems perspective, the same formal processes that operate during a behavioral episode to produce a change from one attractor state to another (e.g., from one facial expression to another) also function to produce developmental change (Lewis, 2000). Furthermore, dynamical systems can be embedded in or overlap with each other. In this way, facial expression may be conceived of as a dynamical system that is itself embedded within a larger complex system that we refer to as "emotion." Behavior thus involves "nested processes that unfold over many timescales from milliseconds to years," and "multiple mutual and continuous interaction of all levels of the developing system" (Thelen & Smith, 2006, p. 258).

Developmental change involves the emergence of new attractor states. This may occur because new constituent components become available to be incorporated into a system either as elements of the system and/or as control variables. Drawing from Thelen's early work on motor development (Thelen, 1985a; Thelen & Ulrich, 1991), walking emerges as a new attractor state when the fat:muscle ratio in the baby's legs achieves its threshold value. The fat:muscle ratio is considered a control variable and the emergence of walking is considered to be a developmental phase shift.

Another principle that may prove useful in understanding emotional ontogeny is that of heterochronic development (Fogel, 1985; Fogel & Thelen, 1987). This means that elements of a system may be present before they become utilized as a component of an attractor state. For example, Thelen (1985a) noted that leg cycling, a behavioral element of walking, is demonstrated by the supine infant well before the emergence of walking itself.

Differentiation and Dynamical Integration in Emotional Development: The DDI Perspective

Drawing on the dynamical systems perspective as well as previous theories, a broad proposal regarding emotional development will be presented. The crux of this proposal is to assert that components of emotion emerge heterochronically during the course of development and become loosely organized into emotion systems (i.e., dynamical systems attractors). Initially, emotions are distinguished primarily in terms of valence (positive or negative, similar—though not identical—to Bridges' 1932 proposal). However, further differentiation occurs as the growing set of available emotion components is reorganized into more specific subsystems via the influence of control parameters. That is, new attractor states emerge that correspond to what are often termed discrete emotions (e.g., anger, sadness, and fear rather than generalized negative affect). These new attractors are assemblies of responses (e.g., appraisals, expressions, neurophysiological responses) including those that DET associates with each of these emotions. Consistent with current epigenetic approaches to development, the universal (or near-universal) appearance of discrete emotions may be considered evolutionary adaptations to universal (or near-universal) environmental circumstances that may serve as "control parameters." Accordingly, discrete emotions might be considered "innate", but not in the traditional sense of the term. Furthermore, in contrast to DET, the DDI perspective does not maintain that these components each develop an exclusive invariant relationship with a discrete emotion under the control of some hard-wired central command system. Importantly, a wide range of "control parameters" may serve to catalyze the progressive reorganizations that occur over the course of development. The emergence of each type of new attractor (i.e., assembly of responses) would be considered a phase shift in dynamical systems terms. Furthermore, the development of each emotion might involve several phase shifts over time so that progressively more elaborated forms of an emotion emerge.

To illustrate this progressive development, an example will be introduced focusing on anger in infants. As described above, recent data indicate that during the first year of life several negative facial expressions (i.e., the MAX-specified infant expressions described for anger, sadness, and physical distress/pain) are produced; yet they appear to be undifferentiated in terms of discrete emotions. That is, overlap in the elicitors for these expressions along with observations of their temporal sequencing during crying suggest that the three facial configurations may all be expressions of generalized negative affect (herein termed "distress"), and that differences in their occurrence may be related to other factors (i.e., control variables) such as respiratory activity and/or the intensity of distress. At the same time, associations between facial expressions and motor activity also have been observed even in early infancy. For example, Camras, Sullivan, and Michel (1993) found that MAX-specified anger and physical distress/pain expressions were associated with more vigorous and jerky motor activity than the sadness expression in their naturalistic study of a 4- to 9-week-old infant. These data are consistent with the possibility that these expressions are synergistically linked with vigorous and jerky (but diffuse) motor activity during early infancy. From the perspective of DDI, this set of synergistically-related responses would be considered a coordinative motor structure. Interestingly, in somewhat older infants, Lewis et al. also have demonstrated associations between MAX-specified anger facial expressions and instrumental arm pulling in their contingent-responding procedure. That is, 2- to 8-month-old infants show increases in both arm pulling and MAX-specified "anger" expressions during extinction episodes (Lewis, Alessandri, & Sullivan, 1990). However, 4- to 5-month-olds also show context-specific dissociations between action and expression, that is, increases in anger expressions but not increases in arm pulling when contingency is followed by loss of contingency (Sullivan & Lewis, 2003). Consistent with the functionalist perspective, these data suggest that infant responses may vary according to their perceived utility (i.e., possibility of generating a desired outcome). From the DDI perspective, the data suggest that as development proceeds, infant responses become differentiated and their integration during an emotion episode will reflect contextual factors as much as the identity of the emotion.

In other research, Bennett, Bendersky, and Lewis (2002, 2005) have demonstrated that elicitor-appropriate specificity in the production of several MAX-specified expressions is low during the first months of life but increases over the course of the first year. That is, the number of babies producing MAX-specified expressions for happiness, anger, and disgust in the appropriate eliciting situation increased over time, while the number of babies producing these expressions in other situations either decreased or remained the same. These data further exemplify the progressive development of associations among different emotion components to form what are conceptualized herein as attractor states.

As children grow, new components of emotion systems as well as new control parameters would be expected to develop. To pursue the "anger" example into the realm of hypothetical possibility, children may produce additional organized reactions to frustration that resemble more prototype-like anger episodes. For example, rather than throwing a temper tantrum consisting of crying and thrashing (i.e., unfocused motor activity), toddlers may direct an intentional attack toward the perceived agent of frustration (e.g., bite or hit him). Such a "mature" anger response requires motor capabilities unavailable to very young infants and also requires the ability to make more sophisticated inferences regarding the intentions and agency of others. However, these several capabilities may be present at an earlier age, that is, before they are organized into an anger episode. That is, some additional factor must be added to the system to "catalyze" the novel organization of responses (i.e., the phase shift) into a system that would be considered to be a more sophisticated form of anger. Several scholars (e.g., Barrett, 2006; Holodynski & Friedlmeier, 2006) have suggested that adult socialization agents may in fact serve this function via modeling, mirroring, contingent responding, and/or use of emotion language during social interaction (see Holodynski & Friedlmeier, 2006, for a review of the relevant research). Because adults will themselves differ in their socialization behaviors (e.g., modeling of anger responding), individual differences (and even cultural differences) in infants' and children's development of anger also might occur. However, the DDI perspective would suggest that further investigation may lead to the identification of previously unsuspected variables that also function as control parameters leading to progressive development of emotions.

The DDI perspective also could explain instances of heterochronicity and differentiation in development that have been observed for emotions other than anger. For example, infant studies indicate that neonatal smiling initially is related to contextual factors that are not typically considered to involve positive emotion (e.g., rapid eye movement [REM] states, Emde & Koenig, 1969). Somewhat later, smiling begins to be produced in situations that are more readily interpreted as reflecting positive affect (see Messinger & Fogel, 2007, for review). As has been observed for negative expressions, further differentiation of smiling also takes place in that different forms (e.g., closed- vs. open-mouth smiles) are associated with different social contexts and thus may reflect different variants of positive affect (Fogel, Nelson-Goens, Hsu, & Shapiro, 2000; Messinger, Fogel, & Dickson, 2001).

Notably, the DDI position described above bears some resemblance to the functionalist perspective on emotion in which response selection depends upon situational requirements for achieving the functional goal of the emotion within the specific situational context. However, the DDI approach admits an even wider range of contextual control factors than does the functionalist perspective (Witherington & Crichton, 2007). For example, beyond relating the presence (or absence) of expressive responses to their potential for communicative functionality, the DDI perspective would acknowledge that expression production might be determined by conditions that have little or nothing to do with emotion communication (e.g., whether an infant is looking upward or downward at a toy). Also worth noting, some elements of the dynamical systems approach have been incorporated into DET in recent years. For example, Izard, Ackerman, Schoff, and Fine (2000) have described "affective-cognitive structures" as dynamically organized assemblies of basic emotions and cognitive constituents. However, in contrast to the DDI position, they retain the notion of innately prewired basic emotions that maintain their inherent structure throughout the lifespan. Lastly, it is important to emphasize differences between the DDI perspective proposed herein and earlier differentiation and integration models of development (Bridges, 1932; Werner, 1948, 1957). While such early approaches first introduced the coupled concepts of differentiation and integration, attention was focused primarily on demonstrating the differentiation process. Drawing from the dynamical systems approach, the DDI perspective gives greater emphasis to the organization (integration) of system components, stressing that such organization is contextually variable and indeed is contextually determined. Thus, newly differentiated patterns of behavior are "softly assembled" rather than rigidly structured. Interestingly, this emphasis holds particular promise in advancing our understanding of individual differences, a "central problem" acknowledged by Werner (1957) in his discussion of the concept of development.

It also is important to acknowledge that future research may necessitate some modification of the DDI position as described herein. For example, in contrast to anger and sadness, the facial expressions related to disgust may not originate in distress-related crying. Instead, disgust-related facial actions may originate as part of a sensory defensive reaction present even in neonates (Peiper, 1963). Thus, while positing a single undifferentiated starting point for the development of all negative emotions may be appealing, we may yet discover that partial differentiation is present from birth (see also Rosenstein & Oster, 1988).

One challenge for the DDI perspective (as well as other theories of emotional development) is to incorporate conscious experience. Dynamical systems-oriented models have been most successful in dealing with observable behavioral responses, and indeed have focused on such responses (e.g., motoric actions, facial expressions). In principle, conscious experience might be considered a potential component of emotion that develops heterochronically and may then be incorporated into an emotion episode. In practice, measuring such conscious experience in infants and young children could present some difficulties. Nonetheless, current developmental studies of self-representation (including its neurophysiological underpinnings and relevance to self-conscious emotions; see Lewis & Carmody, 2008; Lewis, Sullivan, Stanger, & Weiss, 1989) should provide a basis for further research.

Why Adopt a Dynamical Systems Framework?

Proponents of the dynamical systems approach have advocated adopting this framework on several grounds. For example, Thelen and Smith (2006) have argued that the dynamical systems approach provides an innovative way of thinking about development that "abolishes dualities" and embraces multiple determinism on multiple timescales. Nonetheless, many developmental scientists have been rather reluctant to embrace the dynamical systems perspective. In part, this hesitancy may be due to misconception about the necessity of including a formal mathematical modeling component in a dynamical systems research program (see Thelen & Bates, 2003, for a discussion of this issue). However, even more important, many researchers may not perceive an advantage to adopting the dynamical systems approach over other theories or models that currently hold sway in their domain of scholarship. Nonetheless, as emphasized earlier, one credible reason for adopting (or at least considering) a dynamical systems framework is its potential to encourage investigators to direct attention to problematic or "orphan" phenomena in their area of research; that is, phenomena that cannot be easily explained within currently popular theoretical frameworks. That is, investigators might seek to explain such theoretical anomalies rather than attempt to explain them away. Much of the author's research on the development of facial expressions exemplifies this point. However, other potential instances may be noted, including examples drawn from the adult literature. One provocative example starts with the observation that appraisal theories of emotion elicitation may be said (arguably) to dominate that literature. Yet such theories find difficulty in explaining some very interesting emotion phenomena that also have been demonstrated (e.g., effects of pain, extreme temperatures, and even muscular movements on anger responding; see Berkowitz & Harmon-Jones, 2004). Such phenomena could be more easily accommodated within a dynamical systems perspective that emphasizes the importance of synergistic relationships among components of behavior, and the importance of initial contextual conditions on emotional reactions. Adopting a dynamical systems framework also might prove useful in solving the apparent contradiction between the functionality of emotion and the necessity of emotion regulation (Campos, Frankel, & Camras, 2004; Cole, Martin, & Dennis, 2004). That is, from a dynamical systems point of view, one could cut the Gordian knot by eliminating the ontological distinction between them; both "unregulated" and "regulated" episodes of emotion would be viewed as emotion attractor states composed of components that may vary according to contextual demands and developmental history.

Perhaps ironically, one feature of the dynamical systems approach that has engendered some dissatisfaction in the past could be turned into an advantage. Because the dynamical systems approach provides a rather abstract set of concepts and a general theoretical framework (rather than a domain-specific theory), it sometimes has been viewed as too imprecise. However, such imprecision might be considered a virtue in that it allows for maximum flexibility with respect to populating the various concepts (e.g., attractor, control parameter, phase shift) with domain-appropriate instantiations. Furthermore, it might provide a framework within which competing domain-specific theories may be integrated, incorporating the important contributions that each one makes to understanding the particular field of inquiry.

Future Directions

Aside from the DDI proposal described herein, other developmental investigators have utilized a dynamical systems approach to conceptualize and investigate aspects of emotional development in ways that are different from but complimentary to the approach described herein (see Camras & Witherington, 2005, for review). However, much work clearly remains to be done. Arguably, an important next step would be to document the natural history of emotional development more systematically. Similar to the strategy suggested by Thelen and Smith (1994), the process would include tracking the emergence and progressive development of responses that are widely considered to be constituents of emotion (i.e., elicitors, appraisals, neurophysiological responses, instrumental actions, expressive behaviors, and experiential self-reports). This would allow for the identification of emotion attractor states across development as well as the identification of developmental "phase shifts" that might be normative either within or even across cultures. In addition, the natural history of atypical courses of development also might be detailed.

Of course, documenting natural histories is a labor-intensive and painstaking process. Few contemporary researchers have followed the footsteps of early infant diarists such as Charles Darwin (1877), who created a meticulous record of his son's development. Most notable may be Peter Wolff (1987), who made detailed observations of 40 infants in their homes and himself concluded that a dynamical systems framework was most suited to capturing the phenomena he observed. However, with the advent of contemporary recording technology, the potential for recruiting parents as videographers may make it feasible to obtain more extensive records of natural behavior. In addition, researchers might capitalize on the growth of social networking websites on which parents now post video records of their children's emotion reactions. Such records could be used to supplement (or inspire) more systematic studies, possibly leading to the establishment of an emotional development database. Lastly, perusing such episodes might lead to the identification of the type of theoretical anomalies that have been repeatedly emphasized in this article.

Within appropriate ethical boundaries, experimental procedures also should play an important role in establishing a more specific dynamical systems theory of emotional development. Manipulating variables in order to identify synergistic relationships and control parameters has been an important component of dynamical systems studies of motor development. Similarly, manipulating infant gaze direction and mouth opening has proven useful in developmental studies of facial expression. However, designing appropriate laboratory procedures for studying emotional development remains a challenge for investigators.

In conclusion, the dynamical systems approach potentially can provide a framework within which to construct a more comprehensive theory of emotional development. The DDI proposal described in this article represents an initial step in that direction. As much further work clearly remains to be done, the dynamical systems perspective offers rich opportunities for future investigators in order for its promise to be fulfilled.

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