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In Defense of Change Processes

Karen E. Adolph
New York University

Scott R. Robinson
University of Iowa

Nativist and constructivist approaches to the study of development share a common emphasis on characterizing beginning and end states in development. This focus has highlighted the question of preservation and transformation—whether core aspects of the adult end state are present in the earliest manifestations during infancy. In contrast, a developmental systems approach emphasizes the process of developmental change. This perspective eschews the notions of objective starting and ending points in a developmental progression and rejects the idea that any particular factor should enjoy a privileged status in explaining developmental change. Using examples from motor development and animal behavior, we show how a developmental systems framework can avoid the pitfalls of the long and contentious debate about continuity versus qualitative change.

Continuity and Qualitative Change

Every developmental researcher agrees that the primary goal of developmental psychology is to understand development. As described in Kagan (2008), a popular approach to the problem of understanding development is to characterize beginning and end states in a developmental progression and to determine whether important structural and functional features in the initial incarnation are present in the later, adultlike appearance of the skill (Carey, 1991; Pinker, 1984; Spelke & Kinzler, 2007). A variant of this ''stable state'' approach to development is to document multiple stages between beginning and end states and to determine critical similarities and differences among them (Piaget, 1954). The focus on origins, stages, and end states has led researchers from nativist and constructivist frameworks to engage in a long and furious debate about the preservation versus transformation of earlier structures and functions in later, more mature forms. For these researchers, the tension between continuity and qualitative change remains a central issue for understanding development.

In the domain of conceptual development, Kagan points out that arguments for continuity between critical aspects of infants' and adults' conceptual knowledge are based largely on inferences drawn from a relatively lean database: the accumulated duration of young infants' looking times to unexpected visual displays. Based on his discomfort in ascribing conceptual knowledge to young infants based on changes in looking times, Kagan suggests that the notion of qualitative changes in development remains viable. He is in good company: Other researchers have criticized looking times as a basis for inference about infants' conceptual abilities (Bogartz, Shinsky, & Schilling, 2000; Thomas & Gilmore, 2004) and have thus argued in defense of qualitative differences between infant and adult forms in conceptual development.

Ironically, regardless of whether researchers locate themselves on the continuity or discontinuity side of the debate, the focus on characterizing beginning and end states has resulted in a shortage of research on the process of developmental change. The literature is filled with exciting lo-and-behold studies of the earliest manifestations of infants' abilities. Journals and textbooks abound with before and after snapshots of children's remarkably inept behaviors at Time 1 and more mature behaviors at Time 2. However, developmental scientists know surprisingly little about the process of development. Even Piaget's stages—the best-known characterization of children's mental structures—are so exasperatingly bereft of detailed change processes that Klahr (1982) referred to assimilation and accommodation as the ''Batman and Robin'' of developmental psychology (p. 80). Missing are accounts of developmental change processes.

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Correspondence concerning this article should be addressed to Karen E. Adolph, Department of Psychology, New York University, 4 Washington Place, Room 410, New York, NY 10003. Electronic mail may be sent to karen.adolph@nyu.edu.

An alternative, developmental systems framework (Gottlieb, 2007; Oyama, Griffith, & Gray, 2001; Thelen & Smith, 1994) may prove more useful for meeting the goal of understanding development. A developmental systems view sidesteps the debate over continuity and qualitative change—at least as it is formulated with reference to beginning and end states. Periods of relative stability are considered only as benchmarks because stable periods at the ends of a progression may be pushed ever outward or shown to be unstable under less favorable conditions. Common features between earlier and later appearing skills are not accorded privileged developmental status because mature forms are the result of multiple factors, each of which must be at a particular level of readiness. Researchers accept as a matter of course that some structures and functions are preserved (more or less), and some are not.

Most important, a developmental systems framework is concerned with process rather than end products. The focus is shifted from characterizing children's abilities at Time 1 and Time 2 to characterizing the trajectory between the periods of relative stability and the underlying mechanisms of change that shape the developmental path. Arguments about continuity and discontinuity are more likely to arise around the shape of the developmental trajectory, rather than around the preservation of structural or functional features from one time to the next.

Kagan focused on cognitive development and the problem of drawing strong inferences about conceptual structures from small changes in infants' looking times. However, the ideas raised in the article have broad implications for understanding developmental change in other domains. We expand on Kagan's ideas, drawing on evidence from motor development and animal behavior to illustrate our points.

Beginning and End States

Although the theoretical positions of nativism, as exemplified by the work of Spelke and her colleagues (Spelke & Newport, 1998), and constructivism, as exemplified by the work of Piaget and as espoused by Kagan in his target article, are diametrically opposed in terms of the continuity/qualitative change debate, they share a common perspective in discussing development in terms of preservation and transformation. Perhaps the debate is a natural outgrowth of comparing infants to older children or adults: Comparison of performance at Time 1 and Time 2 naturally leads to questions about what remains unchanged and what differs between the two times.

Moreover, both nativist and constructivist traditions share a tendency to reify the beginning and end states in a developmental progression, especially when the ages are sampled from infancy and adulthood. The earliest times at which a particular experimental method can be applied are often interpreted as the starting point for development of the phenomenon, and infants' success in the task is interpreted as core knowledge (Spelke & Kinzler, 2007) or the primary repertoire (cf. Sporns & Edelman, 1993). An arms race has emerged in this game, with methodological advances allowing researchers to tout infants' abilities at earlier and earlier ages.

The assumption of an initial condition and a mature end state in development is not limited to conceptual knowledge, grammar, or other cognitive abilities. In motor development, where structure and form can be observed directly rather than inferred from outward behaviors such as looking times, many researchers also have assumed beginning and end states in development. Adult walking, for example, can be characterized by alternating movements of the limbs within a girdle (the two legs in humans and birds and the forelimbs and hindlimbs in quadrupeds) and by alternating flexor and extensor muscle activation within each limb. Long before infants can walk, however, they can move their legs in alternation. When newborn infants are held upright, they alternate their legs in slow marching movements; while lying on their backs, infants spontaneously kick their legs using many of the same alternating coordination patterns; and ultrasound recordings confirm alternating leg movements in the human fetus (Suzuki & Yamamuro, 1985; Thelen & Fisher, 1982). Before birth or hatching, the rat fetus and chick embryo display alternating leg movements during spontaneous and pharmacologically induced motor activity (Bekoff, 1992; Brumley & Robinson, 2005). Even more dramatic, both adult and infant animal preparations can generate alternating limb activity with spinal cord circuitry alone. Moreover, dedicated neural structures in the spinal cord—termed "central pattern generators" (CPGs)—have a distinct window of development. In the rat, CPGs begin to produce bursts of alternating activity in the spinal nerves that project to limb muscles 3–4 days before birth.

The presence of alternating coordination patterns in the legs and spinal cords of infants and fetuses has led many prominent researchers in motor development to argue that the foundations of locomotion are established prenatally, presumably when CPGs become active (Grillner & Wallen, 2004; Prechtl, 1997). Similarly, Spelke and Newport (1998) in their influential *Handbook* chapter interpreted the early coordination patterns as "inborn, foundational action capacities that persist over development and are common across a great range of animal species" and that "provide the core of humans' ability to locomote" (p. 278). According to this stable state view of motor development, the basic locomotor pattern may be masked at some points in development and later modulated by perceptual feedback and experience, but it remains unchanged in its fundamental form and organization (Grillner & Wallen, 2004).

Change Processes

Regardless of whether researchers lean toward nativism or constructivism, continuity or qualitative change, developmental psychology suffers from a lack of focus on change processes. One suggested solution is that researchers should take seriously the problem of describing the developmental path from Time 1 to Time 2 (Siegler, 2006; Vygotsky, 1978). How does infants' differential looking at an impossible physical event become elaborated or transformed into adults' understanding of physical constraints on objects? How does infants' alternating leg movements develop into running across a cluttered living room floor? A developmental systems approach urges researchers to embrace the challenge of explaining change processes and advocates that they take the idea one step further by rejecting the notion of a privileged factor that is core or foundational in engendering development and by rejecting the assumption of an initial starting point or a mature end state. According to the developmental systems perspective, there are no developmentally special Time 1s and Time 2s. Process is all there is. As stated so eloquently by Hutton (1795) when explaining the geological history of the earth, "we find no vestige of a beginning, no prospect of an end" (p. 80).

Starting and ending points are arbitrary. The rich motor, sensory, and learning abilities of the fetus should render suspect any claims about the primacy of birth in defining initial conditions in development. Other developmental benchmarks such as conception, puberty, and death are salient but not privileged starting or ending points in development. Environmental, organismic, physiological, and genetic factors can exert their influences beyond these boundaries.

Developmental systems researchers address the question of developmental origins by examining the multicausal, multidimensional, and temporally complex details of change processes. For example, it may seem reasonable to locate the developmental roots of sex-typed behavior (e.g., sexual receptivity, aggression) in puberty when the testes and ovaries produce hormones at elevated levels. However, experiments with rodents and other animals that bear multiple offspring indicate that the initial starting point for sex-typical behavior in adulthood can occur long before puberty, before birth, and even before conception. The roots of sex-typed behavior can be located in the rodent dam or in her mother or her mother before her. Female gerbils exhibit masculinized behaviors as adults (display more aggression, more mounting, less receptive lordosis, etc.) if they gestate in a prenatal environment predominated by male fetuses where they are exposed to higher levels of male androgens during sensitive periods of brain development (Ryan & Vandenbergh, 2002). They also exhibit masculinized hormonal development that biases them to produce male-dominated litters themselves, perpetuating the effects of prenatal masculinization across generations (Clark, Karpiuk, & Galef, 1993). Moreover, hormonal exposure is not a privileged factor in sex-typed development. Other effects on sex-typed behaviors can be nonobvious but equally important: Different amounts of maternal licking of rat pups' anogenital region (an important part of maternal care) can bias and accentuate tendencies to express male- or female-typed behaviors later in life (Moore, 1995).

Returning to the example of alternating leg movements in the development of walking, what are we to conclude from the compelling demonstrations of coordinated alternation in neonates and fetuses, the dedicated neural circuitry that seems to underlie the coordination pattern, and the striking similarity between the alternating coordination patterns in infants and adults? From a stable state perspective, the alternating pattern represents a core capacity in adult walking and reveals continuity between beginning and end states (Spelke & Newport, 1998). The developmental systems perspective offers a different interpretation: The activation of a CPG is not a privileged starting point for the development of locomotion, the alternating pattern is no more "core" than the multitude of factors that contribute to the development of walking, and there is no objective end point for adult gait.

The activation of a CPG is not a privileged starting point for the development of walking because alternating bursts of activity in the ventral roots of spinal nerves is not a discrete developmental event. As with all phenomena, the alternating pattern has a developmental history. In the rat fetus, days before spinal nerves show the alternating pattern, the same neural circuitry generates synchronized bursts of activity that result in spontaneous limb movements that are not alternating (Bekoff, 1992). The different patterns likely result from developmental changes in the inhibitory neurotransmitter systems. Gamma-aminobutyric acid (GABA) and glycine, the two most important inhibitory neurotransmitters in the central nervous system, are excitatory rather than inhibitory in the spinal cord of younger fetuses.

Moreover, after the alternating pattern becomes available, it is not obligatory. Human infants spontaneously and deliberately move their legs in a variety of coordination patterns while kicking, crawling, and upright throughout the 1st year. Coordination patterns are plastic and can be flexibly adapted to local conditions. For example, tying rat fetuses' hind legs together with a tiny elastic string shifts the spontaneous pattern of interlimb coordination from alternating to synchronous, and the new pattern is maintained after the string is cut (Robinson, 2005). A similar manipulation shifts the alternating pattern to a synchronous one in human infants (Thelen, 1994).

Alternating leg movements are not a privileged developmental factor in the acquisition of walking. The alternating pattern is only one of the many critical factors that must be in place for infants to walk. The list also includes balance control, muscle strength, appropriate body proportions, sensitivity to visual flow, the ability to detect affordances for upright locomotion, and the motivation to go somewhere (Thelen & Smith, 1994). Each of these factors shares some commonalities and some differences with adult walking, and each has a different developmental time course. For example, although alternation is a key aspect of adult gait in humans, rats, and cats, many mammals that display the alternating pattern during fetal and infancy periods do not alternate their legs as adults (Eilam, 1997). Hopping and bounding are the mature gait patterns of kangaroos, rabbits, and desert rodents such as gerbils, jerboas, and kangaroo rats. More important, the transition from alternation to synchronous hopping occurs postnatally, coincident with rapid changes in leg morphology. From the developmental systems perspective, the goal of developmental analysis is to understand the paths, interrelations, and causal mechanisms of the various time course of each contributing factor.

Defining an end point to development may be an equally difficult enterprise. Structures and functions assumed to be stable features of the adult skill may turn out to be stable only under certain rearing or testing conditions. The structure of adult walking, for example, has been characterized in exquisite detail in terms of inter- and intralimb timing, joint angles, the coordination of flexor and extensor muscle activation, and the dynamic forces produced at each point in the step cycle. However, different rearing and testing conditions can lead to very different end points: A family of adult siblings in Turkey crawl on their hands and feet rather than walk, although walking was physically possible (Humphrey, Skoyles, & Keynes, 2005). A dog born without forelegs developed smooth and functional bipedal locomotion (Stringfellow, 2007). A thousand years of foot binding in China resulted in billions of girls with altered gait patterns to accommodate balance and propulsion on three-inch long feet (Adolph, Karasik, & Tamis-LeMonda, in press). Women in western Kenya have altered the dynamic characteristics of their gait patterns so as to carry tremendous loads on their heads (up to 70% of body weight) with reduced energetic costs (Heglund, Willems, Penta, & Cavagna, 1995). Endurance running is so advanced in the Tarahumaran Indians of the American Southwest that they regularly run the distance of six modern marathons in 1–2 days time (Devine, 1985). Such individual and cultural variations in developmental end points are windows on developmental process and are not as readily accommodated by presumptions of species-typical developmental patterns leading to normal adult behavior.

Methodological Challenges and Conceptual Payoffs

As Kagan reminds us, conclusions about development are only as good as the data. Developmental research has suffered from overreliance on particular experimental paradigms, such as looking time in infants' conceptual development. Strong interpretations about children's knowledge or skills warrant rich data sets derived from convergent behavioral and physiological measures obtained in multiple paradigms. Robust conclusions about the process of change require robust sources of evidence, including adequate sampling to observe change as it occurs.

One strategy for choosing appropriate developmental measures is to use methods that can be applied across a range of ages. The problem with this strategy, as Kagan points out, is that the same measure may reflect different functions or underlying mechanisms at different ages. Kagan suggests that this problem can be avoided by measuring variables at different levels of analysis, presumably closer to the underlying neural and physiological mechanisms governing the response. Physiological measures, such as brain imaging, heart rate, skin conductance, and electromyographic recording, can be sampled across a broad range of ages.

An important caveat, however, is that measurement of variables at lower levels of analysis does not ensure relevance for understanding processes of developmental change. Changes in looking time or any other behavioral measure are accompanied by dramatic changes in body dimensions, physiology, neuroanatomy, neurochemistry, and the growth, interaction, and functioning of cells. These changes are parallel to and deeply interactive with changes in behavior; the direction of causal influence points up and down levels of analysis. Neural, motor, and sensory experiences play dramatic roles in shaping the course of brain development. A developmental systems perspective is particularly helpful from this standpoint because the emphasis on multicausality and multiple levels of analysis emphasizes the need for multiple convergent lines of evidence for characterizing any developing behavior.

Ultimately, we may find no substitutes, only supplements, for direct behavioral assessments, and so the selection of age-appropriate behavioral tasks will remain an important consideration in planning developmental research. In much of the current developmental research, behavioral measures have become more specific and restricted. Kagan points out that total looking time ignores the duration of looking bouts, the number of shifts of attention, the location of eye gaze, and other measures of visual exploration that can be captured from video and eye-tracking recordings. Highly simplified tasks such as change in total duration of looking time facilitate the ease of measuring infant responses but fail to take advantage of infants' rich repertoire of behaviors (e.g., facial expressions, reaching, postural and locomotor responses, social expressions and interactions) that are likely to prove informative when viewed as additional, convergent sources of evidence about infants' perceptions, emotions, and cognitive abilities. Overreliance on a single paradigm may present an overly restricted picture of the diversity of infants' abilities.

A consequence of shifting the focus from identifying beginning and end states to understanding processes of change is choosing appropriate measures and regimes for sampling behavior across development. Surprisingly, the issue of how to make an informed choice about the rate of sampling developmental change has received little attention in developmental psychology. The legacy of nativist and constructivist traditions is that infrequent sampling is viewed as sufficient to identify the major stages and transformations that occur in the course of development. But infrequent sampling can grossly distort patterns of variability and the overall shape of change in the path of development.

Using a data set of infant motor skills sampled daily during the first 18 months and resampled to simulate alternative regimes ranging from 2 to 31 days, we have reported that sampling at rates as frequent as weekly can seriously underestimate the amount of variability relative to daily sampling of motor skills (Adolph, Robinson, Young, & Gill-Alvarez, 2008). Sensitivity to variability is reduced as an inverse power function of the rate of sampling, such that skills that fluctuate between expression and nonexpression 10 or 20 times before achieving a period of stable occurrence erroneously look like single stage-like transformations when indexed weekly or monthly. In fact, 84% of the 261 data sets were characterized by variable trajectories when sampled daily, but 93% appeared to show a single stage-like appearance of the skill when sampled monthly. Estimates of the day of onset of a skill were similarly affected, with errors up to 109 days compared to daily sampling. If developmentalists are to take seriously the challenge of understanding processes of developmental change, then fresh looks at the shape of developmental change will require careful consideration of our methods and rates of collecting developmental data.

In summary, the developing child is a complex and interactive system. The way we view development therefore should transcend simple conceptions of preservation and transformation to characterize patterns and processes of change. We agree with Thelen and Smith (1998) that important progress can be made in understanding change processes if researchers abandon the old dualities such as continuity versus qualitative change and shift their focus to how the developing system works. The developmental systems approach holds additional promise. With a focus on describing the multilayered, multicausal path of development, researchers may gain a better understanding of underlying change mechanisms.

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