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Developmental Cascades

A New Framework to Understand Change

Thus far we have considered the many factors that may contribute to developmental outcomes, such as 11-month-old Marie's first clear utterance labeling of a ball as "bah." As illustrated in earlier chapters, despite the fact that many people (e.g., parents, developmental psychologists, pediatricians) will consider this behavior as an important milestone and the emergence of a new ability, in fact, Marie's first word does not really reflect a sudden qualitative change or a new ability emerging from nothing. Rather, this milestone is a point in a cumulative developmental cascade and reflects the effects of both domain-general mechanisms (e.g., forming associations between different stimuli or properties) and more domain-specific mechanisms (e.g., those specialized for recognizing sound–image associations as *labeling*). During her first year, baby Marie progressed from initially hearing sounds and perceiving phonemes in the speech stream to recognizing segments of fluent speech as familiar by six or seven months of age. At this later age, Marie may have known the "meaning" of some of those sounds (i.e., she recognized the correlation between some words and people or objects), and by 9 or 10 months of age, she certainly was starting to associate words with objects and people. At the same time, baby Marie produced sounds by vocalizing; by six months of age she made distinct speech-like sounds, and eventually those vocalizations could be interpreted as words (e.g., "dada"). Clearly, this sudden onset was not sudden at all. There were many small shifts and changes over the first 11 months of life in Marie's abilities that led up gradually to that first utterance "bah" in reference to a ball. Moreover, these developmental changes occurred across the whole child, reflecting changes in both auditory and visual processing, motor development, representational abilities, and so on. The point is that these are not independent systems that develop on their own trajectory, but rather the development of various systems determines the input into, and provides opportunities for, the development of other systems.

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Although this description may imply a system that is so flexible that it could not possibly lead to consistency across children, as we described in Chapter 4, many factors constrained precisely what Marie learned. Some of these constraints came from the state of Marie's other developing systems: While these language abilities were emerging, Marie was experiencing developmental changes in her visual abilities, from fuzzy vision at birth to, by 4 months of age, vision developed sufficiently to see balls in the environment and distinguish one ball from another. At the same time, Marie was developing an understanding (of sorts) of social interactions. At some point during the first year, Marie started to understand or follow her mother's intent when she pointed at a ball and said "ball." Marie learned to direct her gaze in the direction of a point, as well as the direction of others' gaze, and to associate the sound her mother emitted with some aspect of what she was seeing. This example illustrates that development is messy: Marie's first word only seems to be an abrupt qualitative change if one looks at that behavior in isolation and from a distance.

In short, such developmental achievements represent a point in a cumulative cascade of events—not an endpoint or starting point but rather an achievement at a point in time that both emerges from a number of developmental events and choices that will shape and constrain future developmental events and choices. As just described, Marie's first word reflects the *cumulative consequence* of many interactions and transactions in motor, visual, auditory, social, and cognitive systems. These interactions and transactions also allow Marie to engage in symbolic gestures, increase her conceptual understanding of objects and events, and understand the referents of many words she hears, among other things. Marie's utterance of her first word is a point in an ongoing cumulative developmental trajectory, one that both provides insight into the developmental changes that have led up to this event and an understanding of what developmental changes are now possible and, in some cases, inevitable. We have, in essence, captured a moment in a stream of developmental change that reflects the additive effect of many events, processes, and mechanisms that are ongoing, and this achievement will, in turn, provide opportunities for many additional developmental changes. Moreover, Marie's ability to say "ball" as her first word reflects how this stream was pushed in one direction as a function of a number of factors: She learned English because it was the language she heard, her first word was an object label because of the things that people often refer to when talking to her, and her first word was spoken because she is a hearing infant, exposed to a spoken language, whose articulatory development is typical. At many points in this stream, her development could have been pushed in a different direction if she had heard a different language, if people used fewer or different object names in her presence, or if she had been exposed to a signed language or had a hearing impairment.

To be clear, the production of an infant's first word is a significant achievement, and it does seem to represent a qualitative shift in the individual; specifically, the baby moves from being *prelinguistic* to being *linguistic*, at least in the most primitive sense. This milestone clearly signals a shift in the infant's abilities, is easily identifiable, and represents a change in how others will interact with the infant. Thus, documenting the emergence of milestones such as the first spoken word is important for understanding development. We believe that a complete understanding of the process of development and mechanisms of change requires stepping back to think about how such achievements reflect multiple changes and mechanisms that have occurred at earlier time points and how such achievements make possible other developmental accomplishments at later time points. In this chapter, we will bring together the ideas that we have outlined in the first four chapters and focus in particular on cascades as a general theoretical perspective of developmental change.

Development as Cascades

Consider the cascade depicted in Figure 5.1. The water flows from a common source at the top along several pathways, and it ends up in a broader pool at the bottom. What is most important is that there are multiple pathways that lead to the same general location in the pool; for example, a drop of water that follows a path toward the middle of the image and a drop of water that follows the path on the left of the image both will end up in the pool on the left. In addition, there are multiple places along each path in which trajectories can diverge by traveling to the left or right of a rock. And there are certain paths along which water is more likely to flow than others.

This is how we think about development. Particular outcomes reflect different trajectories, and trajectories diverge in response to different experiences or events as well as the genetic make-up of the child. As an illustration, consider differences in infants' first spoken word. During graduate

Figure 5.1. A cascade, which can be used as a metaphor for thinking about development. Abilities begin at the top of the cascade and move down along different trajectories depending on which rocks and obstacles are encountered along the way. All drops of water, or developing abilities, end up in the pool below, but the particular position in the pool depends on the path traveled, which reflects the events and objects encountered along the path. https://pixabay.com/en/waterfall-lake-river-nature-water-1000158/. Photo CC0 Creative Commons license.

school, one of us knew two assistant professors who each had a baby girl at about the same time. These two infant girls were seen at the lab quite frequently, and the faculty and students in the developmental area grew to know them well. At about one year of age, one of the little girls uttered very clearly "pre-tty" as her first word. Her articulation was clear, she said it as part of a game she played with a mirror, and it was unambiguous. At about the same time, the other little girl would enthusiastically utter "da-ahr" as she pointed to a chair. "Yes, that's a chair," the proud mother would exclaim. The only way that anyone other than this child's mother and father (or other family members and caregivers) understood this as a label for "chair" was if a caregiver was present to provide the context and to interpret the child's utterance. Both children spoke their first word at about one year of age; in essence, they ended up in the left portion of the pool in Figure 5.1 at about the same time. But, the differences in their first utterances suggest that the trajectory of each child was distinct. For example, the fact that one child's first word was an object name (*chair*) and the other child's first word was part of a game or routine (*pretty*) may reflect differences in the language spoken to these two children by their parents and caregivers. The differences in the clarity of the articulation of the first word also may reflect different developmental trajectories. Clearly, their trajectories did not diverge radically (and both girls are now successful and educated adults), but the fact that they did not first utter precisely the same word in the same way suggests differences in the particulars of their developmental trajectories.

This example illustrates how aspects of development involve multiple mechanisms at multiple levels that operate together. For both of the girls we just described, the first utterance reflected the language spoken to them, what they had learned about object names or routines, changes in their articulatory apparatus and control, and many other things. Moreover, changes at one point in time set the stage for changes and developments at another point in time. We believe that we can conceive of many, if not all, developmental outcomes (e.g., the first word, sitting independently, forming a category of "animal") as the result of such forces across time.

Our view of developmental cascades is derived from how this concept has been used in the literature (Masten & Cicchetti, 2010). Typically, developmental cascades have two key characteristics. First, they are used to explain developmental outcomes over very long time periods, and, second, they reflect trajectories across domains or abilities, and often the longitudinal connections involve early events influencing later outcomes in nonobvious ways. For example, Patterson, DeBaryshe, and Ramsey's (1989) dual-failure model predicts that preschool behavioral problems due to poor parenting lead to issues of academic and social competence in school, which, in turn, leads to depressive affect and the risk of relationships with deviant peers who further reinforce antisocial behavior. Other researchers have argued that competence or change in one domain causes competence or change to emerge in a different domain, an idea labeled as positive chain reactions (Rutter, 1999) and skill formation (Heckman, 2006). For example, Bornstein et al. (2013) showed that motoric maturity and active exploration at five months of age predicted academic levels at 14 years of age. Thinking about development in terms of such cumulative cascades has been useful in considering how to facilitate positive developmental change. For instance, pharmacological interventions on behavior can be thought of as attempts to induce an upward cascade in neurochemical changes to influence neural function in the brain that subsequently lead to adaptive behavior (e.g., Charney, 2004; Haglund, Nestadt, Cooper, Southwick, & Charney, 2007).

We argue that this framework can be applied to the developmental changes that occur over days, weeks, and months of infancy and childhood. Consider, for example, the cumulative cascading effects of developing trunk support, independent sitting, independent reaching, and object manipulation and exploration. Infants' developing postural and trunk control leads to the development of self-sitting. This achievement, in turn, causes changes in motor control during reaching; once they can sit independently, infants are free to use their arms and hands to explore their environment, and they now have sufficient trunk control so that they do not topple over as they try to reach for and pick up objects (Rochat & Goubet, 1995; Spencer et al., 2000). In the days and weeks after sitting independently, infants' interactions with objects undergo dramatic changes; as a result, infants' perceptions and conceptions of objects shift (this will be described in more detail in Chapter 7).

Amy Needham's work with the "sticky mittens" procedure (Needham et al., 2002) provides insight into the cascading effects of experience reaching for and picking up objects. Specifically, providing prereaching infants with a short lab session with "artificial" reaching (using sticky mittens) can change their perception of events; infants who have boosted experience reaching for and picking up objects show more sophisticated perception of events involving objects (e.g., Rakison & Krogh, 2012; Sommerville et al., 2005). Examples of the effects of sticky mittens illustrate the fact that changes at one point in time set the stage for changes at a later point in time, whether that point of time is minutes, days, weeks, months, or years later. In the case of providing prereaching infants with sticky mittens, experience with picking up objects provides them the opportunity to learn about the properties of those objects and how they react to physical manipulation. In other domains, changes in muscle control over the lips and tongue provide the opportunity to learn how to articulate speech sounds, and increases in the duration of the information that can be held in working memory provides the opportunity for infants to make connections over information encountered over increasingly long delays. The point is that cascades can occur in the short-term and need not only occur over long developmental timescales.

Note that this is not a focus on longitudinal continuity or stability in individual differences in the same behavior (e.g., children who are more active as infants are more active as preschoolers, and children with a larger reading vocabulary at 6 years have larger reading vocabularies at 10 years). Indeed, observing continuity in individual differences in verbal ability or inhibition over time would not (necessarily) reflect a developmental cascade. Such continuity reflects some particularly stable factor; that is, children have some level of inhibition, and that relative level of inhibition is stable over time.

A cascade approach, instead, is the notion that events that occur at one point in development *set the stage,* or cause a ripple effect, for the emergence or development of different abilities, functions, or behavior at another point in development and do so in a cumulative way. Put another way, the events or developments that occur at one point in a cascade alter the path or trajectory of development, and they provide a context for future experiences, expression of genes, or other factors that will influence or contribute to development. Longitudinal stability of behavior might reflect developmental cascades if they are understood in this way. For example, higher levels of activity in infancy may set the stage for, or push, the developmental path in a particular direction because activity in infancy means that there are more opportunities to explore. Higher activity at a later developmental point might reflect the opportunities that were presented as a function of the earlier high activity level rather than stability in an underlying characteristic of the child.

More intriguing are examples of connections across developmental time in different behaviors. For example, an inhibited child is more likely to have poor or fewer peer interactions during the school-aged years; these peer interactions may put the child at risk for bullying later in development. In Patterson et al.'s (1989) model described earlier, parenting behaviors in the preschool years determine, in part, the level of child behavior problems. These differences in behavior problems create a context for what children will learn, how they will be treated by others, and how they will approach academic tasks when they reach school. Because of these differences in behavior problems, some children are more likely to experience difficulties in social and academic success, which may lead to depression even later in childhood. All of these factors contribute to who children choose as peers, and which peers choose which children, and as a result of this developmental history of parenting, preschool behavior problems, lack of success in school, and depressive affect, these children are more likely to affiliate with deviant peers and engage in antisocial behavior later in childhood.

Similarly, the assessment of motor abilities in five-month-old infants by Bornstein et al. (2013) is not a proxy for later academic achievement. Although it is possible that both increased motor activity and adolescent academic achievement reflect some underlying general maturational factor, such that higher levels of general developmental maturity at five months of age are related to higher levels of general developmental maturity during adolescence, it is more interesting to consider how motoric ability sets the stage for further development by contributing to the cumulative cascade of events that in adolescence is reflected in academic achievement. Higher levels of motoric ability and maturity in infancy may have afforded some children with more opportunities to interact with objects and people as well as more opportunities to explore the physical environment. These opportunities, in turn, lay the foundation for additional experiences and achievements. The relation between motor activity at five months of age and academic achievement at 14 years of age reflects a long chain of developmental events; differences in motor abilities in infants set individuals on different paths that offered variations in opportunities for exploration, perhaps differences in how others interacted with the child, and so on.

The point is that if two infants proceed down distinct developmental pathways, this does not simply reflect dissimilarities in some single factor at one point in time. Rather, a single factor at one point in time may be a good predictor of a developmental trajectory or path—that is, the kinds of experiences and achievements children are likely to have at later points in time—but outcomes at any point in the cascade reflect multiple previous events, contexts, and developments. Particular outcomes at any point set the stage for how future experiences, interactions, and genetic factors, among other things, are interpreted and influence continued development. Thus, individual "outcomes" do not reflect a single factor that predetermined that outcome, but, instead, outcomes vary as developmental trajectories are pushed in different directions.

Such cascades must underlie all of development. As we have discussed, specific achievements such as the production of the first word reflect multiple aspects of earlier development (e.g., auditory, visual, motor, and conceptual processes). Similarly, a toddler's developing ability to put blocks in a shape sorter reflects previous changes in coordinating visual processes (e.g., attending to object shape, perceiving the objects, perceiving the shapes and orientations of the holes in the shape sorter), visually guided reaching, and motor control (e.g., rotating and manipulating the objects to fit it in the holes), among other things. New behaviors are possible not only because processes, structures, functions, and abilities in different domains are coordinated, integrated, and related but also because processes, structures, functions, abilities, *and their* interactions develop over time within the individual. For example, although visually guided reaching begins to emerge in the first half of the first postnatal year, it is not used to put objects in a shape sorter until much later. The interactions among these processes, structures, functions, and abilities change over time, and the interactions at one time determine the development and refinement of processes, structures, functions, and abilities. The crux of this view of developmental cascades is that they involve short- and long-term changes in one or more domains that are caused by changes in those, as well as other, domains.

To make this clear, consider the different developmental trajectories for two infants, one who is tongue-tied and the other who is not. This small physiological difference will determine different paths or trajectories for these two infants from the first postnatal weeks. During these early months, the tongue-tied infant will be less able to explore and manipulate with his or her tongue than will the nontongue-tied infant. As a result, these two infants will develop not only different control over the tongue, but they may also develop different levels of interest in such exploration. The two infants may develop different ways of making sounds, sucking on objects, or mouthing objects during exploratory play. The tongue-tied child may have more difficulty articulating his or her first word (depending on the severity of the tongue-tie, among other things) as a result of these different developmental cascades.

In this way, development reflects *pathways* that are determined, in part, by the particular events, behaviors, and choices that occur at different points in time. A particular pattern of parenting behavior in the preschool years does not predetermine behavior problems, but rather it sets the stage for further development and perhaps biases the developmental trajectory in a particular direction. But later events, such as peer rejection, further determine the direction or trajectory of the developmental pathway, and the "outcome" at any point in time reflects all of these previous events and choices. Similarly, in cognitive development, pathways are shaped by experiences and choices. A young infant who lives with a dog likely spends time looking at that dog and, thus, has more dog experience than an infant who does not live with a dog. When these two infants later encounter a new dog, they may have different levels of interest and/or different strategies for looking at and learning about the new dog (reflecting their different past experience), and, as a result, their representations for dogs—and potentially for other animals and even inanimate objects—continue along different developmental trajectories. Thus, even something ostensibly as minimal as early exposure to a dog in the home may set the stage for adopting a strategy for learning later about other dogs and other animals, but the particular developmental trajectory that occurs reflects many other changes that are ongoing in the infant.

Why Have Developmentalists Not Yet Adopted a Cascade Approach?

Despite the fact that development across domains and time must reflect these cascades, the notion of *developmental cascades* has only been recently (and sparingly) applied to typical perceptual and cognitive development. There are several reasons for this. First, it is impossible to establish that cascade effects are causal despite the use of powerful statistical model testing. All that can be shown by such research is that change or variability in one or more variables is correlated with change or variability in one or more other variables. To address this issue, researchers have tested alternative models, replicated previous findings, or tested plausible third-variable causes for the cascade, but none of these approaches can provide evidence of the causal nature of a cascade effect.

Second, testing cascade effects across long developmental timeframes is time-consuming and expensive. For instance, Bornstein et al. (2006) conducted one large-scale controlled, multivariate, prospective, microgenetic longitudinal study that spanned from infancy to early childhood (covering four years), and Bornstein et al. (2013) performed a similar study that monitored children from infancy to 14 years of age. Such studies are to be applauded, but they are often beyond the scope, in terms of time and resources, of researchers to conduct.

In addition, the discussion of developmental cascades has emphasized *differences* in developmental trajectories, focusing, for example, on trajectories that result in psychopathology or differences in cognitive abilities. It is not immediately clear, therefore, how to adopt this framework to understand typical development across infants that is remarkably similar. In the first 18 postnatal months, most infants acquire the abilities to sit, walk, produce a word or two, point, manipulate objects with two hands, feed themselves, and find hidden objects. Infants all over the world achieve these milestones, regardless of language environment, culture, level of industrialization or technology, or parenting approaches. In other words, despite what appear to be quite large variations in experience and forces on those developmental cascades, change in many areas is highly canalized, and infants achieve milestones in roughly the same time frame despite factors that may push them in one direction or another. This canalization shows how the broad constraints on the system influence development, not how variations in experience alter the developmental trajectory. For example, factors related to the development of the musculoskeletal structure (e.g., nutrition, growth, brain development) constrain when and in what order infants sit, crawl, and walk. But, forces in the cascade can determine this developmental trajectory; the timing of these milestones can be affected by how often infants are allowed freely to explore versus being tightly bound in a crib or other device (Karasik et al., 2015). Such effects are not necessarily a simple delay in overall development; rather, differences in experience causes divergence at some points in the cascade but not others. For instance, sleeping position in US infant samples is related to the timing of the development of some motor milestones such as crawling but not to others such as walking (Davis, Moon, Sachs, & Ottolini, 1998).

Despite the fact that it is difficult to examine developmental cascades directly, adopting this framework to explain development will yield a deeper understanding of developmental change. No aspect of developmental change can be explained by a single causal factor, and therefore we should consider all development as the result of a series of developmental cascades. Every aspect of development results from change across many levels, many modalities, and many domains and is the product of both experience and maturation. Thus, developmental cascades provide a framework to understand change, even if it is not possible to test empirically every full cascade model for every developmental achievement.

Comparison to Other Approaches to Development

How does this view of development differ from other approaches? Comparison to "traditional" developmental perspectives reveals a number of key differences between our view and others. Although we have gained insight from the seminal work of Piaget, Gibson, Vygotsky, and the information-processing perspective, as well as from the careful work conducted in the behaviorist tradition, our view differs in important ways from these traditional theories, and it falls squarely in the center of modern developmental theories. Aspects of our general idea are not new. Clearly, we are borrowing from developmental scientists who examine cascades over long periods of development and attempt to understand maladaptive or atypical outcomes as a function of development over time, although we are also applying cascades to much shorter timeframes and to typical outcomes. But even approaches that have not explicitly talked about development in terms of *cascades* have influenced our thinking.

Our view of development is conceptually similar to Siegler's (1996) idea that change occurs within a domain in a series of o*verlapping waves*. In Siegler's view, new strategies emerge at different times in development, and the child selects which of the available strategies to use based on a given context. In the same way, we view developmental cascades as a series of overlapping waves but across domains such that the emergence of some new skills, function, or ability in one domain facilitates, encourages, or induces the emergence of a different skill, function, or ability in a different domain. These ripple effects are ongoing, concurrent, and multifaceted, and they have long-lasting effects on the child over developmental time. Unlike Siegler's view of the emergence of new cognitive strategies, we propose that cascades are cumulative and occur across domains such that they build to a point that leads to a change in an ability.

We also have been influenced by dynamic systems views of development (Smith & Thelen, 2003; Thelen & Smith, 1994; van Geert, 1998). According to these views, multiple systems develop independently, and new skills or abilities emerge through the coordination of those systems. Moreover, broadly speaking, dynamic systems approaches focus on multiple levels of the system (Witherington & Lickliter, 2017), and central to a systems theory of development is that it is impossible to understand individual components of development without understanding how those components work together (Gottlieb, Wahlsten, & Lickliter, 2007). As a result, dynamic systems theory explains development in terms of the interaction of multiple, often quite disparate systems such as cognition and emotion (Lewis, 1995). The classic example is Thelen's (1995) work on the emergence of walking. In this case, walking emerges not as the result of a predetermined program or the unfolding of a single factor or ability; rather, independent walking depends on reflexive stepping observed at birth, changes in body fat and muscle, postural control, and many other systems. The point is that, like a developmental cascade, the emergence of independent walking reflects the effect of cumulative longitudinal interactions across multiple levels.

Our emphasis on the development of the *whole child* and the recognition of influences across domains, as well as the importance of explaining development at different levels, clearly reflects an influence of these systems theories. In terms of cognitive development, we differ from dynamic systems in that we do not emphasize the construction of in-the-moment cognition (Samuelson et al., 2009; Smith, 2005a); rather, we are interested in understanding how changes over developmental time in multiple domains interact and set the stage for the emergence and refinement of cognitive abilities. In this way, we blend ideas from traditional views, such as Piaget and information-processing, with ideas from systems perspectives.

Most closely related to our view is Linda Smith's discussion of developmental pathways (e.g., Smith, 2013). Building on her influential dynamic systems model of development, Smith proposed that development accumulates, with achievements of the past providing the context and foundation for development into the future. She points out that developing systems are solving many problems at one time, but, nonetheless, there is an orderly nature to development, with new milestones providing the opportunities for further development. She illustrates elegantly how developing explorations of the world, both visually and manually, provide the context for visual object recognition, which, in turn, allows for pretend play and learning of object names. Obviously, this approach is similar in many respects to our own, and our thinking has been shaped by Smith's innovative work. It is worth noting, however, that in contrast to the dynamic systems view and Smith's more recent approach, our view is open to the role of different kinds of constraints as well as the influence of general *and* specific mechanisms on development, and we have described developmental mechanisms as falling along a continuum from very specific to very general (see Chapter 2). Like Smith and others, we recognize the powerful effects of domain-general mechanisms of developmental change. But, we also recognize that some aspects of development may be governed by more specific mechanisms, perhaps that result in biases or preferences present at birth and that have long-term ripple effects on development.

Developmental Cascades in Early Development

Given that cascades have typically been used to describe the long-range influence of changes during early development on later developmental outcomes, it may not be immediately apparent how this view can be applied to changes that occur during infancy. The goal of this section is to describe several specific examples of cascades operating during the period of infancy. The next three chapters will apply in more depth our developmental cascades approach to three aspects of cognitive development; looking behavior in Chapter 6, object knowledge in Chapter 7, and animacy in Chapter 8. However, in the current section, we provide concrete examples of how specific cascades may operate.

Although our emphasis is on development during infancy, many of the developmental cascades that we observe in the first 12 to 24 postnatal months have their origins during prenatal development. For example, prenatal exposure to a particular voice, language, or even a story can set the stage for later development of language processing. Research has revealed significant processing and learning of language during the prenatal period. DeCasper and Spence (1986), for example, found that newborn infants prefer their own mother's voice to another female voice, demonstrating that the mother's voice is heard and learned during fetal development. Other work showed that while in utero the fetus can discriminate between two syllables such /ba/ and /bi/ presented in the words *baba* and *biba* (see Lecanuet & Schaal, 1996) and that newborn infants prefer human language over other nonlanguage sounds (Shultz & Vouloumanos, 2010; Vouloumanos & Werker, 2007). Clearly, therefore, there is evidence that the fetus learns from prenatal exposure to spoken language. This is an important point and makes it clear that abilities and biases present at birth may not be "hard wired" or genetically determined.

Findings of learning and development during the prenatal period also make it clear that newborn infants do not begin processing the input they encounter as a "blank slate." In the context of language, for example, their prenatal exposure to, and learning of, aspects of language (e.g., their mother's voice) begins this cascade and sets the stage for the processing and learning of human voices that will occur after birth. Thus, events and experiences during the prenatal period result in biases or preferences in the newborn; these biases and preferences, in turn, serve as a filter for what information infants are most attentive to and are most likely to process and learn. The effects are potentially far-reaching. The fact that newborn infants begin postnatal life already with biases to listen to familiar languages spoken by familiar voices may be important for language development. In addition, preferences for their own mother's voice may be an important step in a chain of events that contribute to the development of mother–infant attachment over the first year, and their preferences for human speech may induce greater attention to people in general. Enhanced attention to people may, in turn, be an important factor in facilitating language development, social development, emotional development, and so on. Indeed, the fact that a number of key faculties or abilities that underpin language acquisition are present or develop prenatally suggests that developmentalists may gain a deeper understanding into how, why, and when infants are able to produce and comprehend words by considering those attainments in the context of developmental cascades.

Clearly, therefore, learning and development that occurs in one domain at one time in development, even during the prenatal months, may contribute to the cascade of events that determines outcomes at a later time in a different domain. These relations are obvious to parents and others with respect to the achievement of motor milestones. When children acquire the ability to sit unassisted, crawl, or walk, parents often lament how their life is about to change. Consider, for example, the gradual shift over the first postnatal months from an initial reflexive palmar grasp at birth to voluntarily control grasping at about four or five months of age, which allows infants voluntarily to grasp and manipulate objects. This shift represents a significant point of divergence in many developmental cascades. When infants start voluntarily to grasp and manipulate objects, they become able to interact with the world in new ways. These new interactions not only are achievements on their own, but they also provide opportunities for new perceptions of objects because acting on objects may help to make salient features or reactions of objects that were previously unattended or unnoticed. Indeed, milestones such as independent sitting, object manipulation and exploration, and crawling are associated with the attainment of visual perception of objects, depth, and events (Campos, Bertenthal, & Kermoian, 1992; Cicchino & Rakison, 2008; Ross-Sheehy et al., 2016). Even more impressive are findings that show that differences in motor development at one point in time can have effects on developmental outcomes months later; for example, reaching experience early in the first postnatal year can facilitate attention 12 months later (K. Libertus, Joh, & Needham, 2015).

These kinds of relations across time are ubiquitous in early development, and development during infancy has been described for decades in ways that are consistent with this framework. Ainsworth (1979), for example, described the cascading effect of maternal responsiveness across infancy on attachment security at the end of the first postnatal year. Maternal responsiveness to the infant has multiple effects on development: It contributes to infants' developing "working model" of the mother, their increasing sense of security in the world, their emotional state in the moment, and many other things. Each of these effects and consequences provides a context for future interpretations of maternal behavior, future emotional states, future expectations, and so on. How these factors influence additional interactions with the world later further contribute to the development in these different domains. The point is that maternal responsiveness at one point in time may be one episode in a cascade of events that ultimately determines the security of attachment.

In summary, although cascades have typically been used to describe developmental trajectories over very long time spans, we believe this framework is useful for understanding cascades over the weeks and months of infancy. The examples just described illustrate how events, achievements, or experiences at one point in time shape developmental trajectories, influencing development in many domains. As a five-month-old infant interacts with her mother, she builds a representation of those interactions, contributing to the foundations of a working model of her relationship with her mother. She also experiences emotional responses, contributing to the development of her emotional well-being. She may begin to learn contingencies between her own actions and outcomes and develop a sense of self-agency and an understanding of cause-and-effect relations. These interactions at five months of age set the stage for many future developments both in the short-term (e.g., in the next hour, next day, or next week) while at the same time (or perhaps as a result of those short-term effects) have far-reaching consequences on the infants' relationships, emotional development, and cognitions about cause and effect months or years down the line.

The examples discussed here also illustrate how cascades are not restricted to a narrow domain but may be useful for characterizing development in many different domains. As infants develop physically, achieve motor skills, acquire cognitive abilities, and enhance their emotional experiences, each developmental change is a step in a pathway toward other developmental changes. Although our discussion in this book is focused on early cognition because that is our area of expertise, we believe that this framework will provide useful in areas other than cognitive development.

Cascades and the Shape of Developmental Change

We have used the word *cumulative* thus far in many instances to describe cascades because they are often best characterized by an accumulation of abilities that lead to change. However, it is important to point out that although we adopt a cascade approach for change, we do not think that development proceeds only in one direction. It would be easy to think of cascades in development as starting at one point (e.g., the top of a waterfall) and moving steadily downstream toward another point (the pool below). Look back at Figure 5.1. Think about what happens to a particular drop of water as it moves from one point in the cascade to another. Certainly, that drop moves steadily toward its goal: however, the drop also moves laterally, depending on the obstacles and opportunities in its path. Moreover, the drop may hit a surface and bounce *up*, momentarily moving in a direction *away* from the end goal and back toward the starting point. This is how we think about development. Development does not simply follow observable behaviors that increase in complexity and sophistication over time. Rather, development follows along a complex path, and it is characterized by many different-shaped trajectories. The most frequent developmental trajectory observed is characterized by a general improvement in an ability, either by the onset of that ability or skill or by a refinement or increase in efficiency or complexity of a skill (see Figure 5.2, Panel A). For example, children before their first birthday are more or less unable to say any words; they then develop the ability to say a small handful of words; and between 18 and 24 months, there is a naming explosion in which children seem to be constantly acquiring new words. Vocabulary growth, therefore, shows a trajectory from the absence of an ability to the presence and rapid growth of an ability. This is quite typical in development across the lifespan and characterizes children's learning to read, to do addition, stack blocks, and manipulate cutlery. However, because this trajectory is expected, it is unremarkable. Showing that infants and toddlers become better at a skill or acquire more knowledge is relatively predictable; after all, any parent can tell you that their child could not, for example, walk or talk and then they could.

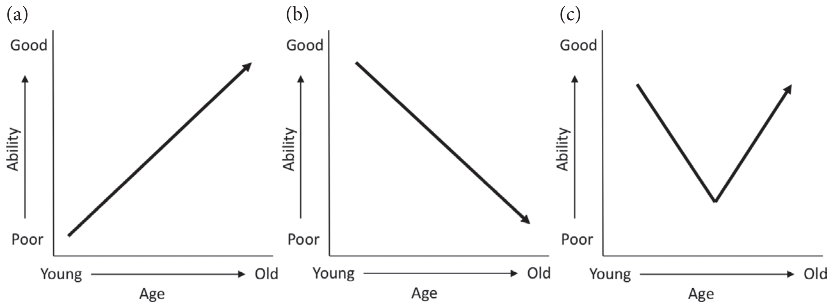

Figure 5.2. Schematic depictions of different possible developmental trajectories.

Such changes are, nonetheless, as we have argued the result of a cascade of upward changes such that the emergence and improvement over time of an ability is the causal result of many other positive changes across the infant. In other words, this kind of trend likely reveals a cascade effect whereby the cumulative changes that occurred upstream led to a positive increase in the abilities of the infant. An improvement in information-processing abilities, ever more fine-grained perceptual abilities, and increasingly sophisticated motor skills, among other things, are likely to lead to the emergence of new abilities, knowledge, skills, and strategies. This idea is entirely consistent with the notions of positive chain reactions (Rutter, 1999) and skill formation (Heckman, 2006) such that change in one or more domains leads to progressive changes in a different domain; in this book, we have described such effects as cumulative cascades.

Developmental trajectories can take other shapes, however. Perhaps less intuitive is the pattern of change whereby young infants are able to do something and then that ability is "lost" and older infants are unable to do that thing (see Figure 5.2, Panel B). This is the developmental trajectory associated with the phenomenon of, among other things, *perceptual narrowing*. In perceptual narrowing, infants initially show broad or unspecific perception (e.g., the ability to perceive differences between sounds of many languages or to differentiate between individual human faces and between individual monkey faces) and gradually their perception becomes narrow or specific to their experience. The classic example of this effect is found in infant speech perception research. Werker and Tees (1983, 1984) observed that although 6-month-old infants exposed only to English could detect speech distinctions in both English and Hindi, 10- to 12-month-old infants exposed only to English could detect only those distinctions in English. Just an additional four to six months of experience hearing English caused infants to *narrow* their perception of speech sounds, and as a result they were sensitive only to the sounds within their "native" language. This trajectory has repeatedly been observed in speech perception as well as other domains. For example, Pascalis, De Haan, and Nelson (2002) found that although 6-month-old infants were equally able to discriminate between two human faces or between two monkey faces, 10-month-old infants were more selective and only could discriminate between two human faces. This broad-to-narrow trajectory has been observed in other contexts, including infants' recognition of object function (Madole & Cohen, 1995), associating symbols to words (Namy & Waxman, 1998), and expectations of the features of agents (Rakison, 2005b).

These examples clearly can be thought of in terms of developmental cascades. Infants' initial abilities reflect the state of, and interaction between, their cognitive, perceptual, motor, and other systems, and their abilities change as their experience (and maturation) shapes how they use those abilities. In the case of speech perception, the newborn's ability to discriminate between different speech sounds reflects the prenatal development of the auditory system. The "starting state" of the newborn auditory system allows them to discriminate between the sounds of many different languages. This starting state, coupled with biases created from prenatal exposure to human (maternal) speech, shapes infants' experience with language in the first postnatal months. As they hear and process the speech sounds of a particular language (i.e., the language spoken around them), infants' perception of speech changes: Their auditory system becomes tuned specifically to the sounds of the language they are hearing. The cascade of events that lead to this fine-tuning and, in essence, a "reduction" in ability must reflect changes in the networks formed in the auditory system through the development of constraints at a perceptual and neurological level as well as infants' ability to extract statistical regularities in the speech stream. This developmental trajectory can be thought to reflect a cascade of events.

Other development shows U- or N-shaped developmental trajectories (see Figure 5.2, Panel C; for a review, see Rakison & Yermolayeva, 2011). Such now-you-see-it-now-you-don't trajectories are puzzling. Why would infants show an ability at one age, lose that ability, only to have it remerge at a later age? Although not common, these trajectories have been observed across a range of domains including preschooler's acquisition of grammar

(Pinker, 1994) and infants' face perception (Cashon & Cohen, 2004). In the acquisition of verb forms, for example, children sometimes initially utter correct forms of irregular verbs ("I went to school"), sometime later overregularize and incorrectly apply the rule to that irregular verb ("I goed to school"), and later still learn when to apply the rule appropriately, uttering the correct version of the irregular verb ("I went to school"). Once again, such trajectories are consistent with a cascade framework. When young children are in the early stages of language development, they acquire and learn specific examples of words. Their use of those words in different contexts provides them with information about statistical regularities and rules. This allows children to learn the rule for the regular form of the past tense (i.e., add "–ed" to the verb) and to learn by rote the irregular forms. However, because children's information-processing abilities are limited, they fail to recall from memory the irregular version of a verb and fall back to use the rule they have learned about regular verbs; this leads to the kinds of verb errors described. Finally, children's implicit understanding of syntax develops, as well as other information-processing abilities, which allow them again to exhibit adultlike use of the verb form. In some sense, this interpretation is consistent with Patterson et al.'s (1989) dual-failure model such that two key failures—failing to retrieve the correct irregular past-tense verb form from memory and the use of the regular past tense rule—predicts children's incorrect use of the verb.

These nonlinear U-shaped or N-shaped developmental curves also may result from developmental cascades. Indeed, such developmental trajectories are often explained in terms of different underlying abilities and processes contributing to behavior at different ages. This notion is central to our cascades approach; behavior in a skill or ability changes over time as the result of the cumulative influences of changes in multiple domains. As an example, consider Rakison's (2005b) investigation of infants' ability to learn whether *agent* or *recipients* in causal launching events have moving parts. Significantly, in the real world, *agents* have moving parts, but recipients do not necessarily have moving parts. Rakison observed that both 12- and 16-month-old infants failed to learn that recipients had moving parts in these events, but 14-month-old did learn this association. This inverted U-shaped curve reflects a *cascade* of events in infants' understanding of agents and recipients in causal events.

Importantly, the 12-month-old infants in Rakison's (2005b) study did not learn that agents had moving parts. This suggests that their failure to learn that recipients have moving parts reflected a general inability to learn which actor in the event had moving parts. Infants at 12 months of age may be unable to learn such relations because their information-processing abilities (e.g., short- and long-term memory, encoding speed, attentional control) are not sufficiently developed to allow them to track this regularity in these events. The 16-month-old infants, in contrast, did learn that agents had moving parts. These oldest infants selectively learned the association that was most consistent with their daily experience with agents and causal action. That is, their *failure* to learn that recipients had moving parts reflected a different set of processes and experiences that had changed over time. The 14-month-old infants showed an intermediate pattern, learning *both* that agents had moving parts *and* that recipients had moving parts. This sensitivity to both relations presumably reflects increased information-processing abilities compared to the 12-month-old infants, but this learning was unconstrained by experience with agents and recipients in the world. Thus, they have not yet formed the biases that constrain the associations learned by the oldest infants. This pattern must be the cumulative effect of cascades of changes that occur across the infant, including changes in information-processing abilities, maturation, experience, and potentially locomotor behavior, language skills, and social interactions.

Considering the shape of development, or different developmental trajectories, provides an understanding into development more broadly. Clearly, these examples raise important questions about focusing on age-related changes alone. Age is a proxy for many things that happen over the course of development: physical maturation, changes in the brain and nervous system, increased experience, and exposure to more input, among other things. When we observe that, for example, six- and nine-month-old infants respond differently to a set of stimuli or in a particular task, it is impossible to know which of those many factors is responsible for that difference. Indeed, it can be difficult to know whether the same processes are engaged when infants of different ages respond in the *same* way to stimuli. As just described, the 12- and 16-month-old infants observed by Rakison (2005b) both failed to learn the association between moving parts and the recipient of an action but apparently for different reasons. In the context of face perception, researchers have assumed that because both six- and nine-month-old infants discriminate between examples of own-race faces (as evidenced from their novelty preference) that they must be doing so by using the same processes and mechanisms (Kelly et al., 2005, 2007).

However, there is another possibility: The novelty preference may reflect different perception, recognition, and discrimination processes at the two ages. Young infants may use a general strategy to discriminate faces in a novelty preference task; their strategy is effective at discriminating among faces of many different types. Over time, infants learn how to use different strategies to discriminate faces such that older infants may direct their attention to different kinds of features, use different brain structures (perhaps taking advantage of connectivity that was not yet in place in the earlier months), and so on. They can apply these new strategies to the processing of *familiar* stimuli—because, after all, that was the context in which these strategies developed—but they are unable to use these strategies to the processing of relatively unfamiliar stimuli. As a result, it appears as though the ability to perceive faces from familiar races or species is *maintained* and the ability to perceive faces from unfamiliar races or species is *lost*. This description raises the possibility that discrimination of faces changes over developmental time, and the new strategies are most effective for familiar faces.

Considering the shape of the developmental pathway may also provide insight into not only *that* an ability develops but *why* the ability develops when and how it does. It has been argued that perceptual narrowing reflects the fine-tuning of brain regions in response to experience with processing stimuli of a particular type (Scott, Pascalis, & Nelson, 2007). It also has been suggested that perceptual narrowing reflects the adoption of new attentional and learning strategies in response to experience (Bosseler et al., 2013). However, perceptual narrowing does not seem to reflect a permanent change in the system, at least in the first 12 months of life. Fair, Flom, Jones, and Martin (2012), for example, demonstrated that the effects of perceptual narrowing can be reversed by manipulating the experimental design, and Pascalis et al. (2005) showed that the perceptual narrowing effect can be staved off with additional experience of the to-be-lost discriminations. These studies show (at least for infants' discrimination of monkey faces) that perceptual narrowing does not seem to reflect a permanent change in the perceptual system. Rather, it is a response from a fluidly changing system of interactions among many mechanisms—some cognitive, some perceptual, and some neurological—that give rise to different patterns of development.

The point we are making here is that documenting that some ability does or does not change across age is a first step in understanding development. We need to dig deeper and understand how the ability, process, or skill in question has been shaped by learning, is affected by changes at multiple levels of processing, and is influenced by structural, environmental, and cognitive constraints. In other words, we need to recognize how a documented change reflects or builds on other observed changes, involves mechanisms in the same and other domains, and is influenced by the specific learning infants and young children might have had as well as their genetic make-up. This perspective will lead to a greater understanding of *development* and the mechanisms of change. In our view, a cascade perspective can provide insight into why children undergo different developmental trajectories: These trajectories reflect how many different mechanisms interact, with some of these interactions leading to a general increase in the level of an ability and others leading to less monotonic changes in an ability.

Summary

In this chapter, we have brought together the issues raised in the first four chapters to discuss development in terms of cascades. These cascades, we argue, underpin every aspect of development change from walking to talking to playing to thinking. By adopting a developmental cascade approach, we can gain insight into the key questions of developmental science that have largely remained unsolved and uncover new questions that developmentalists should be asking about change. The focus is not on when change occurs but rather *how* change is the result of a multitude of factors across a range of levels and systems in the developing child. In the next section of the book, we apply this framework to infant looking behavior (Chapter 6), object knowledge (Chapter 7), and animacy (Chapter 8). In the final chapter, we show how our cascade perspective can be applied more broadly to development in infancy and beyond.