BRAIN DEVELOPMENT

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Fischer, K. W., & Bidell, T. (2006). Dynamic development of action and thought. In W. Damon & R. Lerner (Eds.), *Handbook of Child Psychology, Vol. 1: Theoretical Models of Human Development* (6th ed., pp. 313-399). Hoboken, NJ: John Wiley & Sons.

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Modern approaches to the study of brain development reveal an active, dynamic process

Unlike the predominant conceptions from a few decades back, brain development is currently understood to be an active, dynamic process, involving complex interactions between a person's biological predispositions, physical environment and social nurturance. Rather than a hardwired, purely genetically programmed system, a child's experiences actively organize her brain over time, in accordance with biological principles and constraints (Johnson, 2001). In turn, the child's own neuropsychological profile of strengths and weaknesses shapes the way she perceives and behaves in the world. As she grows and develops, physiological and socio-cultural processes work together in intricate, nuanced patterns to sculpt her brain's development.

While some aspects of neurological development do appear to proceed in a linear, step-by-step way, such as the organization of neurons into cortical layers during prenatal growth, in general the development of the distributed neural systems that underlie complex psychological phenomena rarely shows this lock-step, ladder like developmental trajectory. Instead, children's experiences shape the growth and functioning of complex networks of brain areas that are recruited and connected as a child actively constructs cognitive, social, and emotional skills for understanding and acting in the world. The development of these skills is dynamic, with characteristic fluctuations in skill level depending on the emotional, social, cognitive and physical context in which the person is acting.

For example, as a baby learns to crawl, neural networks connecting the frontal, parietal, and occipital brain areas responsible for coordinating motor, somatosensory and visual information show a large spurt in EEG coherence, a measure of functional connectivity (Bell & Fox, 1996). That is, as the child grapples to master the skill of crawling, electrical activity produced by the neurons in these distant brain regions becomes increasingly synchronized, a process that is thought to reflect the growth of a neural network by which neurons in motor and sensory cortices can connect with and influence each other in order for the infant to crawl. Once the baby becomes skilled at crawling, the degree of intra-hemispheric coherence decreases again, as extra connections are pruned. In this way, the connectivity and growth of the brain happens in dynamic cycles that reflect the development of a person's skills and behaviors in context. As the baby's skill for crawling is initiated, stabilized and automated, networks in the brain grow and prune to facilitate the organization of her behavior.

Brain development involves building distributed neural networks to support skills

As children grow and develop, they build skills for understanding and acting on the world (e.g. Fischer & Bidell, 2006; Piaget, 1954). The cognitive functions that come together to make these skills, for example for crawling, for phonological decoding in reading, or for persuading one's father to give her one more cookie before bed, are instantiated in the brain, and involve the recruitment of many processing areas distributed in many parts of the brain. Related to the complexity of the neural networks that support functional skills, there also is growing evidence for variability in the neuropsychological systems different learners use to build their skills.

This modern view is quite different from the traditional localizationist account of brain function, in which cognitive functions were mapped in one-to-one correspondence onto specific locations in the brain, with the young brain composed of distinct, preformed modules or faculties. Learning is now understood to involve the formation of connections of networks in various regions of the brain. While specific brain areas do carry out particular types of processing, real-world skills are embodied in the networks they recruit, rather than in any one neural location. For example, there is no language, emotion, or mathematics area of the brain that is not also involved in processing many other domains of knowledge.

Because of the constructive, neurally-distributed nature of learning, there appear to be various routes to effective skill development, especially in the case of complex skills such as reading, math, or social processing. Children are resourceful in recruiting their neuropsychological strengths to build the skills they need to live, and although many common skills are similar across people with similar developmental experiences, there is also good evidence that people can adapt their neuropsychological capacities to learn skills in diverse ways. For example, Immordino-Yang (Immordino-Yang, 2007) studied compensation for basic skills in two adolescent boys who had recovered from the surgical removal of an entire cortical hemisphere to control intractable seizures. She found that each boy had compensated for neuropsychological weaknesses by transforming important skills into new ones that accommodated his remaining neural strengths. In a similar vein, while most children learn to read by developing a particular sequence of educationally-relevant skills such as rhyming and phoneme-graphing matching, many children learn to read by following alternate pathways, with more or less success (Knight & Fischer, 1992).

Brain development is shaped by both emotional and cognitive processing

As we have seen, the development of neuropsychological skills involves recruiting and connecting functional networks across the brain into organized systems that underlie complex and varied behavior. Of necessity, for these complex skills to be appropriately and adaptively engaged involves not only cognitive but also emotional brain systems (Immordino-Yang & Damasio, 2007). For example, think again of the infant learning to crawl. The skill of crawling involves coordinating networks for motor planning and control, somatosensation, and vision, distributed within the frontal, parietal and occipital lobes of the brain. However, in addition to these networks, we must consider that the infant's skill is constructed within an emotional and social context—the baby sees something out of reach that she wants to play with, or her father calls her over to climb up on his lap, and she uses her newly developing skill for crawling to get the interesting toy or go to her father. In this way, the development of the baby's skill for crawling is driven by the desirable or adaptive function that the crawling will serve for her—the baby crawls because she *wants* to, or because she *needs* something or someone, or to move away from something she fears. In each of these cases, the neural systems supporting emotion and attention work together with those supporting cognition to shape the development of the neural networks underlying the skill.

Studies of brain development can inform developmental psychological theories and applications to education and clinical practice

The modern study of brain development is coming increasingly to inform and constrain theories of cognitive and emotional development, most notably in the fields of developmental psychology and education. Because many areas spanning both hemispheres of the brain are involved in real-world cognitive or emotional tasks, the question of how experience serves to organize specialized networks for complex tasks like crawling, reading or social perspective-taking becomes pertinent to our understanding of brain development. In the other direction, an understanding of the neural systems underlying a particular skill can afford new insights into the development and functioning of that skill. For example, in learning to read Knight & Fischer (1992) found that while a majority of children follow a normative developmental pathway in which they coordinate skills for letter identification and for rhyming into a more general skill for reading, other children follow less common and less efficient pathways in which the skill for rhyming develops separately from the skills for recognizing letters and reading. Since this early study, there has been an explosion of work on the neural systems underlying each of these components of reading, as well as significant progress in relating the development of these systems to literacy acquisition (Katzir & Pare-Blagoev, 2006), with the aim of helping dyslexic and normal children become more effective readers.

A new approach: Human nature and nurture are intertwined in brain development

In recent years, the advent of new tools and technologies for studying brain development (e.g. fMRI for children) has precipitated the establishment of a new interdisciplinary approach that integrates neuroscientific with developmental psychological methods and practical applications, such as in educational contexts. This approach, known as the field of Mind, Brain and Education, presents a much more complex landscape in which to study brain development—one in which social nurturance, culture, and other experiences shape the mind and brain in a dynamic interaction with a person's genes (Fischer, et al., 2007). As we saw in the crawling example, mind-level skills and their underlying brain networks act as dynamic systems, continually changing to reflect the situation, wants and needs of the person as she lives and learns in context. Children are born with a propensity for different types of neural processing, and brain development involves the active construction and specialization of neural networks to handle cognitive and emotional skills for thought and action in that child's physical and social world.

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