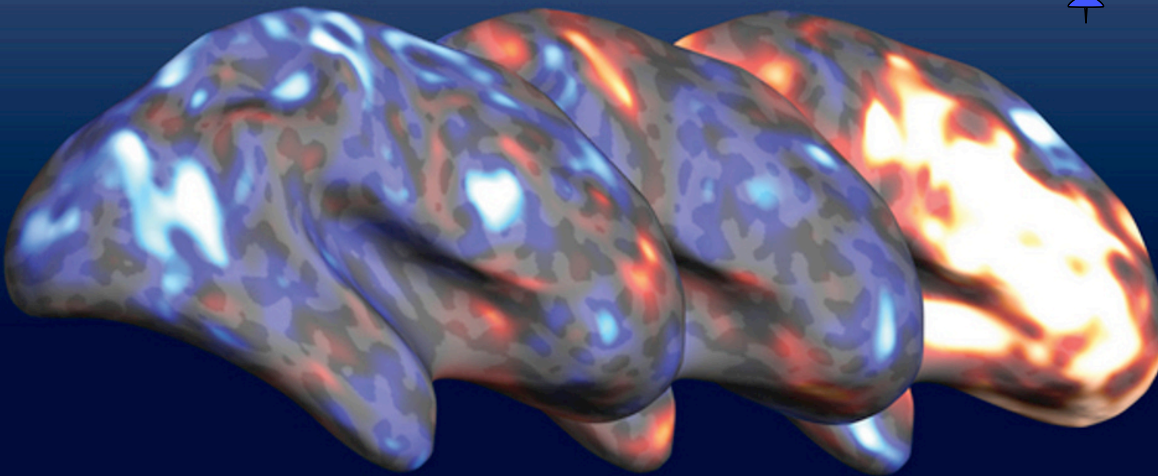

DEVELOPMENTAL COGNITIVE NEUROSCIENCE

Fourth Edition

Mark H. Johnson and
Michelle de Haan

with website

WILEY Blackwell

Developmental Cognitive Neuroscience

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An Introduction

Fourth Edition

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Michelle de Haan

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To our parents, who provided both our nature and our nurture.

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Preface to the First Edition

In the first chapter of this book I describe some of the factors responsible for the recent emergence of a subdiscipline at the interface between developmental psychology and cognitive neuroscience. I have chosen to refer to this new field as "developmental cognitive neuroscience," though it has been known under a number of other terms such as "developmental neurocognition" (de Boysson-Bardies, de Schonen, Jusczyck, McNeilage, & Morton, 1993). Though a series of edited volumes on the topic has recently appeared, like most newly emerging disciplines there is a time lag before the first books suitable for teaching appear. This book and the Reader which I edited in 1993 (Johnson, 1993) are initial attempts to fill the gap. While some may believe these efforts to be premature, my own view is that the lifeblood of any new discipline is in the students and postdocs recruited to the cause. And the sooner they are recruited, the better.

Is developmental cognitive neuroscience really significantly different from other fields that have a more extended history, such as developmental neuropsychology or cognitive development? Clearly, it would be unwise to rigidly demarcate developmental cognitive neuroscience from related, and mutually informative, fields. However, it is my belief that the emerging field has a number of characteristics that makes it distinctive. First, while there is some disagreement about exact definitions, the fields of developmental neuropsychology and developmental psychopathology focus on atypical development, while commonly comparing them to normal developmental trajectories. In contrast, cognitive neuroscience (including the developmental variant outlined in this book) focuses on normal cognitive functioning, but uses information from deviant functioning and development as "nature's experiments" which can shed light on the neural basis of normal cognition. This book is therefore not intended as an introduction to the neuropsychology of developmental disorders. For such information the reader is referred to the excellent introductions by Cicchetti and Cohen (1995) and Spreen, Risser, and Edgell (1995).

Second, unlike many in cognitive development, this book adopts the premise that information from brain development is more than just a useful additional source of evidence for supporting particular cognitive theories. Rather, information about brain development is viewed as both changing and originating theories at the cognitive level. Third, developmental cognitive neuroscience restricts itself to issues at the neural, cognitive, and immediate environmental levels. In my view it is a hazard of some interdisciplinary fields that the focus of interest is diffused across many different levels of explanation. This is not to deny the importance of these other levels, but a mechanistic interdisciplinary science needs to restrict both the domains (in this case aspects of cognitive processing) and levels of explanation with which it is concerned. Finally, developmental cognitive neuroscience is specifically concerned with understanding the relation between neural and cognitive phenomena. For this reason, I have not discussed evidence from the related field of developmental behavior genetics. In general, developmental behavior genetics tends to be concerned with correlations between the molecular level (genetics) and gross behavioral measures such as IQ. With some notable exceptions, little effort is made to specifically relate these two levels of explanation via the intermediate neural and cognitive levels. Having pointed out the different focus of developmental cognitive neuroscience, my hope is that this book is written to be both accessible and informative to those in related and overlapping disciplines.

The above comments go some way to explaining the choice of material that I have presented in the book. However, I have no doubt that there is a substantive amount of excellent experimentation and theorizing that could have been included but was not. Since this is intended as a brief introduction to the field, I have chosen to focus on a few particular issues in some detail. Of course, the choice of material also reflects my own biases and knowledge since the book is intended as an introductory survey of the field as viewed from my own perspective. I apologize in advance for the inevitable omissions and errors.

The book is aimed at the advanced-level student and assumes some introductory knowledge of both neuroscience and cognitive development. Students without this background will probably need to refer to more introductory textbooks in the appropriate areas. I also hope that the book will attract developmentalists with an interest in learning more about the brain, and cognitive neuroscientists curious as to how developmental data can help constrain their theories about adult functioning. But most of all I hope that the book inspires readers to find out more about the field, and to consider a developmental cognitive neuroscience approach to their own topic.

Preface to the Fourth Edition

In the nearly two decades since publication of the first edition of this book, the field of developmental cognitive neuroscience (DCN) has continued to expand very rapidly, and the volume of papers published in specialized and generalist journals make the job of reviewing and summarizing this information increasingly formidable. In addition, the range of evidence encompassed within the field now extends to the underlying genetics and epigenetics. Thus, and as in previous editions, the selection of material inevitably involves our biases, but with a focus on topics in which a specifically DCN approach has been taken. This inevitably means that there are topics in the parent disciplines of cognitive development or developmental neuroscience that are not addressed in this book.

As the field matures, researchers and funders are increasingly interested in applying the knowledge we have gained to practical real-world problems, such as developing the best brain-based strategies for formal school education. Thus, in this fourth edition we have emphasized new research that underpins application to important clinical, educational, and societal issues. In particular, we have added a new chapter on the emerging topic of educational neuroscience (Chapter 12).

In line with the previous edition, we include "key discussion points" at the end of each chapter, which can be used in association with the teachers' website associated with the book (www.wiley.com/go/johnson/dcn) that has essay, short answer, and multiple choice test questions as well as downloadable figures. Also, as in previous editions, we provide many pointers to further reading, allowing the book to be used as a springboard for more detailed exploration of the field.

We continue to be indebted to many colleagues and collaborators for educating and informing us on a variety of topics. We also thank our publisher for their continued commitment to the book and Luba Prout for her invaluable contribution to the production of this edition.

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Abbreviations

2D	two-dimensional
ADHD	attention deficit/hyperactivity disorder
ANS	approximate number system
ASL	American Sign Language
BOLD	blood oxygen level dependent
CA1	cornu ammonis 1 area of the hippocampus
CA3	cornu ammonis 3 area of the hippocampus
CANTAB	Cambridge Neuropsychological Testing Automated Battery
COMT	catechol-O-methyltransferase gene
CT	computed tomography
DAT1	dopamine active transporter 1 gene
DLPC	dorsolateral prefrontal cortex
DNA	deoxyribonucleic acid
DSP4	N-(2-chloroethyl)-N-ethyl-2-bromobenzylamine neurotoxin
DTI	diffusion tensor imaging
EEG	electroencephalography, electroencephalogram
ERO	event-related oscillations
ERP	event-related potential
FEF	frontal eye fields
FFA	fusiform face area
FG	fusiform gyrus
FMR1	gene Fragile X mental retardation 1 gene
fMRI	functional magnetic resonance imaging
FOXP2	gene forkhead box protein P2 gene
GABA	gamma-aminobutyric acid
GBG	Geschwind, Behan, and Galaburda model of hemispheric differences
HD	high density
HD-ERP	high-density event-related potential
HM	initials of a patient with amnesia
IMM/IMVH	intermediate and medial part of the mesopallium
IPS	intra parietal suclus
IQ	intelligence quotient

IS	interactive specialization
ISI	interstimulus interval
KBCC	knowledge-based cascade correlation
LGN	lateral geniculate nucleus
LTC	lateral temporal complex
MGN	medial geniculate nucleus
MNS	mirror neuron system
MPFC	medial prefrontal cortex
MRI	magnetic resonance imaging
MT	middle temporal visual cortical area
MTL	medial temporal lobes
NIRS	near infrared spectroscopy
PET	positron emission tomography
PFC	prefrontal cortex
PKU	phenylketonuria
RNA	ribonucleic acid
SES	socioeconomic status
SIPN	Social Information Processing Network
SLI	specific language impairment
SOA	stimulus onset asynchrony
SP	spike potential
STS	superior temporal sulcus
TPH2	tryptophan hydroxylase gene 2
TV	television
V1	primary visual cortex
VWFA	visual word form area
WS	Williams syndrome

About the Companion Website

This book is accompanied by a companion website:

www.wiley.com/go/johnson/developmentalcognitiveneuroscience

The website includes:

- Multiple choice questions and an answer guide

The material is available freely but you will need an instructor password to access the answers to the multiple choice questions.

1 The Biology of Change

In this introductory chapter we discuss a number of background issues for developmental cognitive neuroscience, beginning with historical approaches to the nature–nurture debate. Constructivism, in which biological forms are an emergent product of complex dynamic interactions between genes and environment, is presented as an approach to development that is superior to accounts that seek to identify preexisting information in genes or the external environment. However, if we are to abandon existing ways of analyzing development into “innate” and “acquired” components, this raises the question of how we should best understand developmental processes. One scheme is proposed for taking account of the various levels of interaction between genes and environment. In addition, we introduce the difference between innate representations and architectural constraints on the emergence of representations within neural networks. Following this, a number of factors are discussed that demonstrate the importance of the cognitive neuroscience approach to development, including the increasing availability of brain imaging and molecular approaches. Conversely, the importance of taking a developmental approach to analyzing the relation between brain structure and cognition is reviewed. In examining the ways in which development and cognitive neuroscience can be combined, three different perspectives on human functional brain development are discussed: a maturational view, a skill learning view, and an “interactive specialization” framework. Finally, the contents of the rest of the book are outlined.

Developmental Cognitive Neuroscience: An Introduction, Fourth Edition. Mark H. Johnson and Michelle de Haan. Published 2015 by John Wiley & Sons, Ltd.
Companion website: www.wiley.com/go/johnson/developmentalcognitiveneuroscience

1.1 Viewpoints on Development

As every parent knows, the changes we can observe during the growth of children from birth to adolescence are truly amazing. Perhaps the most remarkable aspects of this growth involve the brain and mind. Accompanying the fourfold increase in the volume of the brain during this time are numerous, and sometimes surprising, changes in behavior, thought, and emotion. An understanding of how the developments in brain and mind relate to each other could potentially revolutionize our thinking about education, social policy, and disorders of mental development. It is no surprise, therefore, that there has been increasing interest in this new branch of science from grant-funding agencies, medical charities, and even presidential summits. Since the publication of the first edition of this book in 1997, this field has become known as *developmental cognitive neuroscience*.

Developmental cognitive neuroscience has emerged at the interface between two of the most fundamental questions that challenge humankind. The first of these questions concerns the relation between mind and body, and specifically between the physical substance of the brain and the mental processes it supports. This issue is fundamental to the scientific discipline of *cognitive neuroscience*. The second question concerns the origin of organized biological structures, such as the highly complex structure of the adult human brain. This issue is fundamental to the study of *development*. In this book we will show that light can be shed on these two fundamental questions by tackling them both simultaneously, specifically by focusing on the relation between the postnatal development of the human brain and the emerging cognitive processes it supports.

The second of the two questions above, that of the origins of organized biological structure, can be posed in terms of *phylogeny* or *ontogeny*. The phylogenetic (evolutionary) version of this question concerns the origin of species and has been addressed by Charles Darwin and many others since. The ontogenetic version of this question concerns individual development within a life span. The ontogenetic question has been somewhat neglected relative to phylogeny, since some influential scientists have held the view that once a particular set of genes has been selected by evolution, ontogeny is simply a process of executing the "instructions" coded for by those genes. By this view, the ontogenetic question essentially reduces to phylogeny (e.g., so-called evolutionary psychology). In contrast to this view, in this book we argue that ontogenetic development is an active process through which biological structure is constructed afresh in each individual by means of complex and variable interactions between genes and their respective environments. The information is not in the genes, but emerges from the constructive interaction between genes and their environment (see also Oyama, 2000). However, since both ontogeny and phylogeny concern the emergence of biological structure, some of the same mechanisms of change have been invoked in the two cases.

FURTHER READING Oyama (2000).

The debate about the extent to which the ontogenetic question (individual development) is subsidiary to the phylogenetic question (evolution) is otherwise known as the nature–nurture issue, and it has been central in developmental psychology, philosophy, and neuroscience. Broadly speaking, at one extreme the belief is that most of the information necessary to build a human brain, and the mind it supports, is latent within the genes of the individual. While most of this information is common to the species, each individual has some specific information that will make them differ from others. By this view, development is a process of unfolding or triggering the expression of information already contained within the genes.

At the opposing extreme, others believe that most of the information that shapes the human mind comes from the structure of the external world. Some facets of the environment, such as gravity, patterned light, and so on, will be common throughout the species, while other aspects of the environment will be specific to that individual. It will become clear in this book that both of these extreme views are ill conceived, since they assume that the information for the structure of an organism exists (either in the genes or in the external world) prior to its construction. In contrast to this, it appears that biological structure emerges anew within each individual's development from constrained dynamic interactions between genes and various levels of environment, and it is not easily reducible to simple genetic and experiential components (Scarr, 1992).

It is more commonly accepted these days that the mental abilities of adults are the result of complex interactions between genes and environment. However, the nature of this interaction remains controversial and poorly understood, although, as we shall see, light may be shed on it by simultaneously considering brain and psychological development. Before going further, however, it is useful to review briefly some historical perspectives on the nature–nurture debate. This journey into history may help us avoid slipping back into ways of thinking that are deeply embedded in the Western intellectual tradition.

Throughout the 17th century there was an ongoing debate in biology between the "vitalists" on the one hand and the "preformationists" on the other. The vitalists believed that ontogenetic change was driven by "vital" life forces. Belief in this somewhat mystical and ill-defined force was widespread and actively encouraged by some members of the clergy. Following the invention of the microscope, however, some of those who viewed themselves as being of a more rigorous scientific mind championed the preformationist viewpoint. This view argued that a complete human being was contained in either the male sperm ("spermists") or the female egg ("ovists"). In order to support their claim, spermists produced drawings of a tiny, but perfect, human form enclosed within the head of sperm (see Figure 1.1). They argued that there was a simple and direct mapping between the seed of the organism and its end state: simultaneous growth of all the body parts. Indeed, preformationists of a religious conviction argued that God, on the sixth day of His work, placed about 200,000 million fully formed human miniatures into the ovaries of Eve or sperm of Adam (Gottlieb, 1992)!

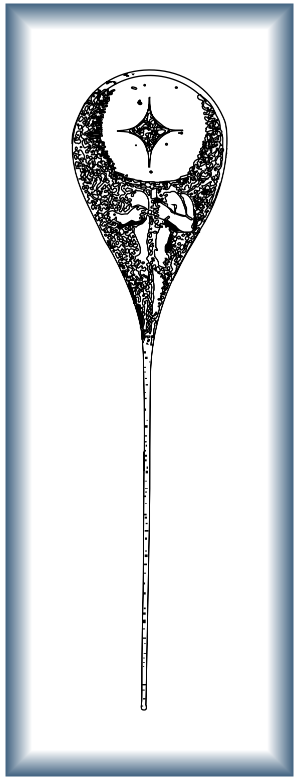

Figure 1.1 Drawings such as this influenced a seventeenth-century school of thought, the "spermists," who believed that there was a complete preformed person in each male sperm and that development merely consisted of increasing size.

Of course, we now know that such drawings were the result of overactive imagination and that no such perfectly formed miniature human forms exist in the sperm or ovaries. However, as we shall see, the general idea behind preformationism, that there is a preexisting blueprint or plan of the final state, has remained a pervasive one for many decades in biological and psychological development. In fact, Oyama (2000) suggests that the same notion of a "plan" or "blueprint" that exists prior to the development process has persisted to the present day, with genes replacing the little man inside the sperm. As it became clear that genes do not contain a simple "code" for body parts, in more recent years, "regulator" and "switching" genes have been invoked to orchestrate the expression of the other genes. Common to all of these versions of the nativist viewpoint is the belief that there is a fixed mapping between a preexisting set of coded instructions and the final form. We will see in Chapter 3 that we are discovering that the relationship between the genotype and its resulting phenotype is much more dynamic and flexible than traditionally supposed.

On the other side of the nature–nurture dichotomy, those who believe in the structuring role of experience also view the information as existing prior to the end state, only the source of that information is different. This argument has been applied to psychological development, since it is obviously less plausible for physical growth. An example of this approach came from some of the more extreme members of the behaviorist school of psychology who believed that a child's psychological abilities could be entirely shaped by its early environment. More recently, some developmental psychologists who work with computer models of the brain have suggested that the infant's mind is shaped largely by the statistical regularities latent in the external environment. While such efforts can reveal hitherto unrecognized contributions from the environment, it will become evident in this book that these computer models can also be an excellent method for exploring types of interaction between intrinsic and extrinsic structure.

Further Reading Mareschal, et al. (2007); Munakata, Stedron, Chatham, & Kharitonova (2008).

The viewpoints discussed above share the common assumption that the information necessary for constructing the final state (in this case, the adult mind) is present prior to the developmental process. While vitalists' beliefs were sometimes more dynamic in character than preformationists', the forces that guided development were still assumed to originate with an external creator. Preformationism in historical or modern guises involves the execution of plans or codes (from genes) or the incorporation of information from the structure of the environment. Oyama (2000) argues that these views on ontogenetic development resemble pre-Darwinian theories of evolution in which a creator was deemed to have planned all the species in existence. In both the ontogenetic and phylogenetic theories of this kind, a plan for the final form of the species or individual exists prior to its emergence.

A more recent trend in thinking about ontogenetic development is constructivism. Constructivism differs from preformationist views in that biological structures are viewed as an emergent property of complex interactions between genes and environment. Perhaps the most famous proponent of such a view with regard to cognitive development was the Swiss psychologist Jean Piaget. The essence of constructivism is that the relationship between the initial state and the final product can only be understood by considering the progressive construction of information. This construction is a dynamic and emergent process to which multiple factors contribute. There is no simple sense in which information, either exclusively in the genes or in the environment, can specify the end product. Rather, these two factors combine in a constructive manner such that each developmental step will be greater than the sum of the factors that contributed to it. The upshot of this viewpoint is not that we can never understand the mapping between genetic (or environmental) information and the final product, but rather that this mapping can only be understood once we have unraveled some of the key interactions that occur between genetic and environmental factors during ontogeny. Unfortunately, this means that there are unlikely to be quick breakthroughs in understanding the functions of regions of the human genome for psychological development.

FURTHER READING Piaget (2002); Mareschal et al. (2007).

Until recently the constructivist view suffered from the same problem as vitalism, in that the mechanisms of change were poorly specified and the emergence of new structures from old resembled the conjuror's trick of making a rabbit appear from a hat. Even the "mechanisms" proposed by Piaget appeared somewhat elusive on closer inspection. Another problem with the constructivist approach was that, despite its emphasis on interaction, it was unclear how to analyze development in the absence of the traditional dichotomy between innate and environmental factors. By taking a cognitive neuroscience approach to psychological development, in conjunction with a number of new theoretical approaches, we will see that it is now possible to flesh out the constructivist approach to development and to provide new ways to analyze cognitive and brain development.

1.2 Analyzing Development

Viewpoints on cognitive development that involve reducing behavior to information derived from genes, on the one hand, and/or information derived from the external environment, on the other, have commonly used the distinction between "innate" and "acquired" components. The term "innate" is actually rarely explicitly defined, and it has a somewhat checkered history in developmental science. Indeed, the term has been dropped from use, or even actively banned, in some areas of developmental biology. The main reason for the term having been dropped from use in fields of biology such as ethology and genetics is because it is simply no longer useful, since it has become evident that genes interact with their environment at many different levels, including the molecular. One compelling example of this point, discussed by Gottlieb (1992), concerns the formation of the beak in the chick embryo.

The production of the (toothless) beak in the chick embryo results from the coaction of two types of tissue. However, if, in an experimental situation, one of these types of tissue (mesenchyme) is replaced with the same tissue from a mouse, then teeth will form rather than a beak! Thus, as Gottlieb (1992) points out, the genetic component that is necessary for the chick to produce teeth has been retained from the reptilian ancestry of birds. More generally, the phenotype that emerges from these genes in the chick can vary dramatically according to the molecular and cellular context in which they are located.

FURTHER READING Gottlieb (2007).