

# Predictive coding and attention in developmental cognitive neuroscience and perspectives for neurodevelopmental disorders

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## ABSTRACT

Sensory prediction and repetition suppression are closely related cognitive mechanisms that allow the brain to form predictions about the environment, and guide perception in synergy with attention. Predictive coding is a theory of the fundamental role of predictive mechanisms in brain functions. Authors have proposed a central role of predictive impairments in autism and possibly other neurodevelopmental disorders. However, little is known about predictive mechanisms in typical development, and how they co-develop with attention. Here we review experimental support for predictive coding and its links with attention in healthy adults' brains, the first experimental works performed in typically developing children and infants, and theoretical accounts of neurodevelopmental disorders using a predictive coding framework. We propose future directions for predictive coding research in development. Finally, we describe the first predictive coding experiments in neonates and provide research perspectives for using this framework in searching for early markers of atypical neurodevelopment.

## 1. Introduction

Neurodevelopmental disorders (ND) are a group of psychiatric disorders that concern 1–17 % of the population worldwide (François et al., 2022) and represent a growing medical and social challenge. They are characterized by sensory, cognitive, or social impairments that lead to disabilities and school difficulties and include autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), learning disorders, intellectual disability, communication disorders, and motor disorders (Crocq and Guelin, 2015). We are still far from understanding how these disabilities emerge, hindering our ability to implement early screening and preventive interventions that would be necessary to limit high-severity symptoms. Many theories were proposed to explain ND origins, mostly for ASD (Lawson et al., 2014; Noél and Angelaki, 2023), and evidence for prenatal origins is accumulating (Bonnef-Brihault et al., 2018), but there is no consensus to date. However, several authors have recently put forward that many of the symptoms, particularly the earliest, prodromal ones, could be explained by deficits in predicting sensory inputs (Cruys et al., 2014; Lawson et al., 2014; Pellicano and Burr, 2012; Sinha et al., 2014). This proposal is built on the predictive coding theory, a theoretical framework proposing the brain's prediction abilities, as first formulated by H. Helmholtz, are the basis of all

cognitive functions (Friston, 2005). In parallel, there has been a growing interest in predictive coding from authors working on neonatal and infant sensory processing and cognition, such that it is time to review this line of research and outline future directions for cognitive scientists working with neonates or searching for early markers of ND.

After introducing predictive coding concepts that are useful for neurodevelopmental cognitive neuroscience, we review the main experimental studies supporting this model and illustrate its mechanisms with experimental findings in adults. We provide schematic representations of the relationships between predictive coding concepts and electroencephalography (EEG) event-related potentials (ERPs). In doing so, we intend to make it easier for the reader to relate the concepts to experimental data, which to our knowledge has not been provided by previous reviews on predictive coding. This work provides a common framework for interpreting ERP data in the typical subject, but also a reference for observations in atypical or developing populations. Moreover, formalizing the correspondence between cognitive concepts and ERPs should facilitate the inclusion of future work in the integrative framework of developmental cognitive neuroscience. We feature relevant findings from other modalities such as fMRI and DMR, although we could not provide an exhaustive review of these modalities in the scope of this work. The long-term aim is to complete the diagrams with

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# Neurodevelopmental Disorders Developmental Cognitive Neuroscience

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## **Neurodevelopmental Disorders Developmental Cognitive Neuroscience:**

**Neurodevelopmental Disorders** Helen Tager-Flusberg, 1999 Until recently genetic neuroanatomical and psychological investigations on neurodevelopmental disorders were carried out independently Now tremendous advances across all disciplines have brought us toward a new scientific frontier the integration of molecular genetics with a developmental cognitive neuroscience The goal is to understand the basic mechanisms by which genes and environmental processes contribute to the development of specific structures and regions of the brain **BOOK JACKET** This handbook style volume explores these advances from the perspective of developmental disorders in children **BOOK JACKET** *Neurodevelopmental Disorders Across the Lifespan* Emily K. Farran, Annette Karmiloff-Smith, 2011-12-15 Nowadays it is widely accepted that there is no single influence be it nature or nurture on cognitive development Cognitive abilities emerge as a result of interactions between gene expression cortical and subcortical brain networks and environmental influences In recent years our study of neurodevelopmental disorders has provided much valuable information on how genes brain development behaviour and environment interact to influence development from infancy to adulthood This is the first book to present evidence on development across the lifespan across these multiple levels of description genetic brain cognitive environmental In the book the authors have chosen a well defined disorder Williams syndrome WS to explore the impact of genes brain development behaviour as well as the individual s environment on development WS is used as a model disorder to demonstrate the authors approach to understanding development whilst being presented in comparison to other neurodevelopmental disorders Autism Developmental Dyscalculia Down syndrome Dyslexia Fragile X syndrome Prader Willi syndrome Specific Language Impairment Turner syndrome to illustrate differences in development across neurodevelopmental disorders Williams syndrome is particularly informative for exploring development Firstly it has been extensively researched at multiple levels genes brain cognition and behaviour as well as in terms of the difficulties of daily living and social interaction Secondly it has been studied across the lifespan with many studies on infants and toddlers with WS as well as a large number on children adolescents and adults The authors also explore a number of domain general and domain specific processes in the verbal non verbal and social domains across numerous neurodevelopmental disorders This illustrates among other factors the importance of developmental timing i e that the development of a cognitive skill at a specific timepoint can impact on subsequent development within that domain but also across domains In addition the authors discuss the value of investigating basic level abilities from as close to the infant start state as possible presenting evidence of where cross syndrome comparisons have shed light on the cascading impacts of subtle similarities and discrepancies in early delay or deviance on subsequent development Designed such that readers with an interest in any neurodevelopmental disorder can gain insight into the intricate dynamics of cognitive development the book covers both theoretical issues and those of clinical relevance It will be an invaluable reference for any researcher clinician student as well as interested parents or teachers

wishing to learn about neurodevelopmental disorders from a developmental framework

### **Developmental Cognitive**

**Neuroscience** Mark H. Johnson, 2011-07-18 The third edition of Developmental Cognitive Neuroscience presents a thorough updating and enhancement of the classic text that introduced the rapidly expanding field of developmental cognitive neuroscience Includes the addition of two new chapters that provide further introductory material on new methodologies and the application of genetic methods in cognitive development Includes several key discussion points at the end of each chapter Features a greater focus on mid childhood and adolescence to complement the previous edition's emphasis on early childhood Brings the science closer to real world applications via a greater focus on fieldwork Includes a greater emphasis on structural and functional brain imaging

### **Developmental Cognitive Neuroscience** Michelle D. H. de Haan, Iroise

Dumontheil, Mark H. Johnson, 2023-04-03 Landmark text focusing on the development of brain and behavior during infancy childhood and adolescence Developmental Cognitive Neuroscience provides an accessible introduction to the main methods theories and empirical findings of developmental cognitive neuroscience The focus is on human development from in utero to early adulthood but key comparative work is also included This new edition covers research in clinical medical populations educational applications and major advancements in methods and analysis in particular with increasing longitudinal research focusing on understanding the mechanisms of cognitive development It also contains a new chapter on global and cross cultural perspectives outlining how developmental cognitive neuroscience has been applied in different settings and how techniques can be successfully adapted The text features a variety of student friendly features such as chapter end discussion applications of basic research and introductions to key experimental methods An accompanying related resource website for students and educators that includes a test bank of multiple choice questions is also provided Other sample topics covered in Developmental Cognitive Neuroscience include Biology of change methods and populations from gene to brain building a brain and vision orienting and attention Perceiving and acting in a world of objects learning and long term memory language and prefrontal cortex working memory and decision making Perceiving and acting in the social world educational neuroscience interactive specialization and integrating development cognitive neuroscience Mid childhood and adolescent development social cognition and neuroimaging and broader cognitive neuroscience approaches and theory With expansive yet accessible coverage of the subject Developmental Cognitive Neuroscience is an ideal resource for upper level undergraduate and early postgraduate readers The text will further appeal to professionals in fields that have adopted developmental cognitive neuroscience approaches such as education clinical psychology pediatric medicine and global health

**The Oxford Handbook of Developmental Cognitive Neuroscience** Kathrin Cohen Kadosh, 2024-06-24 The Oxford Handbook of Developmental Cognitive Neuroscience brings together the leading developmental cognitive neuroscientists in the field that work on understanding human development and the complex interplay of genetic environmental and brain maturational factors that shape social and cognitive functioning in development It includes chapters on new emerging

research areas that show promise for understanding both brain and behaviour in development such as nutrition and the microbiome gut brain axis and sleep Looking beyond early developmental changes this handbook also places importance on the period of adolescence which is an important developmental juncture By assuming complexity from the outset the developmental cognitive neuroscience research approach provides much needed insights into both the initial set up of brain networks and cognitive mechanisms and also into adaptability across the developmental trajectory This is important not only for scientists studying typical and atypical development but also for interventional work looking for critical or sensitive periods where interventions would be most effective The developmental cognitive neuroscience research approach intersects nature and nurture and considers both health and disease models It also focuses on understanding the complexity of human development necessitating a multi level and multi factor research approach to grasp change and plasticity which by definition is multidisciplinary The Oxford Handbook of Developmental Cognitive Neuroscience is a landmark volume providing the reader with a comprehensive and state of the art overview of current research in the field whilst highlighting current gaps and directions for future research

**Taking Development Seriously A Festschrift for Annette Karmiloff-Smith** Michael S. C. Thomas, Denis Mareschal, Victoria Knowland, 2021-05-16 This influential festschrift honours the legacy of Annette Karmiloff Smith a seminal thinker in the field of child development and a pioneer in developmental cognitive neuroscience The current volume brings together many of the researchers collaborators and students who worked with Professor Karmiloff Smith to show how her ideas have influenced and continue to influence their own research Over four parts each covering a different phase or domain of Karmiloff Smith's research career leading developmental psychologists in cognition neuroscience and computer science reflect on her extensive contribution from her early work with Piaget in Geneva to her innovative research project investigating children with Down syndrome to understand the mechanisms of Alzheimer's disease The chapters provide a mix of cutting edge science and reminiscence providing a fascinating insight into the historical contexts in which many of Annette's theoretical insights arose including such ideas as the microgenetic approach representational redescription and neuroconstructivism The chapters also provide updates about how earlier theoretical ideas have stood the test of time and present unpublished data from the early years of Annette's career Taking Development Seriously is essential reading for students and scholars in child development and developmental neuroscience

**Developmental Cognitive Neuroscience** Mark H. Johnson, Michelle de Haan, 2015-04-21 Developmental Cognitive Neuroscience 4th Edition is a revised and updated edition of the landmark text focusing on the development of brain and behaviour during infancy childhood and adolescence Offers a comprehensive introduction to all issues relating to the nature of brain behaviour relationships and development New or greatly expanded coverage of topics such as epigenetics and gene expression cell migration and stem cells sleep and learning memory socioeconomic status and development of prefrontal cortex function Includes a new chapter on educational neuroscience featuring the latest findings on the

application of cognitive neuroscience methods in school age educational contexts Includes a variety of student friendly features such as chapter end discussion practical applications of basic research and material on recent technological breakthroughs

**Autism and Joint Attention** Peter C. Mundy, 2016-03-01 From a preeminent researcher this book looks at the key role of joint attention in both typical and atypical development Peter C Mundy shows that no other symptom dimension is more strongly linked to early identification and treatment of autism spectrum disorder ASD He synthesizes a wealth of knowledge on how joint attention develops its neurocognitive underpinnings and how it helps to explain the learning language and social cognitive features of ASD across the lifespan Clinical implications are explored including reviews of cutting edge diagnostic methods and targeted treatment approaches

**Atypical Cognitive Deficits in Developmental Disorders** Sarah H. Broman, Jordan Grafman, 2014-02-25 This volume is based on a conference held to examine what is known about cognitive behaviors and brain structure and function in three syndromes and to evaluate the usefulness of such models The goal of this endeavor is to add to the knowledge base of cognitive neuroscience within a developmental framework Most of what is known about the neurological basis of cognitive function in humans has been learned from studies of central nervous system trauma or disease in adults Certain neurodevelopmental disorders affect the central nervous system in unique ways by producing specific as opposed to generalized cognitive deficit Studies of these disorders using neurobiological and behavioral techniques can yield new insights into the localization of cognitive function and the developmental course of atypical cognitive profiles The focus of this book is a discussion of the multidisciplinary research findings from studies of autism and Williams and Turner syndromes The approaches methods techniques and findings reported are at the cutting edge of neuroscience research on complex behavior patterns and their neural substrates Each disorder is accompanied by some degree of general cognitive impairment or mental retardation Of greater interest are the atypical deficits in which a cognitive function is spared such as language in Williams syndrome or is disproportionately depressed as are spatial discrimination skills and visual motor coordination in Turner syndrome Drastically reduced or seemingly absent language capabilities and little interaction with other people characterize the core autism syndrome A comprehensive and critical discussion of appropriate statistical techniques is made vivid by examples given from studies of small groups or single subjects in neurolinguistics and related fields

**Attention, Genes, and Developmental Disorders** Kim Cornish, John Wilding, 2010-08-12 What is attention How does it go wrong Do attention deficits arise from genes or from the environment Can we cure it with drugs or training Are there disorders of attention other than deficit disorders The past decade has seen a burgeoning of research on the subject of attention This research has been facilitated by advances on several fronts New methods are now available for viewing brain activity in real time there is expanding information on the complexities of the biochemistry of neural activity individual genes can be isolated and their functions identified analysis of the component processes included under the broad umbrella of attention has become increasingly sophisticated and

ingenious methods have been devised for measuring typical and atypical development of these processes from infancy into childhood and then into adulthood In this book Kim Cornish and John Wilding are concerned with attention and its development both typical and atypical particularly in disorders with a known genetic etiology or assumed genetic linkage Tremendous advances across seemingly diverse disciplines molecular genetics pediatric neurology child psychiatry developmental cognitive neuroscience and education have culminated in a wealth of new methods for elucidating disorders at multiple levels possibly paving the way for new treatment options Cornish and Wilding use three specific yet interlinking levels of analysis genetic blueprint genotype the developing brain and the behavioral cognitive outcomes phenotype as the basis for charting the attention profiles of six well documented neurodevelopmental disorders ADHD autism fragile X syndrome Down syndrome Williams syndrome and 22q11 deletion syndrome Their overarching aim in this book is to provide the most authoritative and extensive account to date of disorder specific attention profiles and their development from infancy through adolescence

**Interdisciplinary Approaches to Altering Neurodevelopmental Disorders** Wadhera, Tanu, Kakkar, Deepti, 2020-03-13 Disorder assistive and neurotechnological devices are experiencing a boom in the global market Mounting evidence suggests that approaches based on several different domains should move towards the goal of early diagnosis of individuals affected by neurodevelopmental disorders Using an interdisciplinary and collaborative approach in diagnosis and support can resolve many hurdles such as lack of awareness transport and financial burdens by being made available to individuals at the onset of symptoms Interdisciplinary Approaches to Altering Neurodevelopmental Disorders is a pivotal reference source that explores neurodevelopmental disorders and a diverse array of diagnostic tools and therapies assisted by neurotechnological devices While covering a wide range of topics including individual centered design artificial intelligence and multifaceted therapies this book is ideally designed for neuroscientists medical practitioners clinical psychologists special educators counselors therapists researchers academicians and students

*Handbook of Child Psychology and Developmental Science, Cognitive Processes*, 2015-03-31 The essential reference for human development theory updated and reconceptualized The Handbook of Child Psychology and Developmental Science a four volume reference is the field defining work to which all others are compared First published in 1946 and now in its Seventh Edition the Handbook has long been considered the definitive guide to the field of developmental science Volume 2 Cognitive Processes describes cognitive development as a relational phenomenon that can be studied only as part of a larger whole of the person and context relational system that sustains it In this volume specific domains of cognitive development are contextualized with respect to biological processes and sociocultural contexts Furthermore key themes and issues e g the importance of symbolic systems and social understanding are threaded across multiple chapters although every each chapter is focused on a different domain within cognitive development Thus both within and across chapters the complexity and interconnectivity of cognitive development are well illuminated Learn about the inextricable intertwining of perceptual development motor

development emotional development and brain development Understand the complexity of cognitive development without misleading simplification reducing cognitive development to its biological substrates or viewing it as a passive socialization process Discover how each portion of the developmental process contributes to subsequent cognitive development Examine the multiple processes such as categorizing reasoning thinking decision making and judgment that comprise cognition The scholarship within this volume and as well across the four volumes of this edition illustrate that developmental science is in the midst of a very exciting period There is a paradigm shift that involves increasingly greater understanding of how to describe explain and optimize the course of human life for diverse individuals living within diverse contexts This Handbook is the definitive reference for educators policy makers researchers students and practitioners in human development psychology sociology anthropology and neuroscience

**Disorders of Language Development** Pasquale J. Accardo, Brian T. Rogers, Arnold J. Capute, 2002

Brain Lateralization and Developmental Disorders Ivanka Asenova, 2018-01-09 Brain Lateralization and Developmental Disorders provides a comprehensive review of key findings and speculations from previous research on atypical cerebral lateralization in the most common neurodevelopmental disorders stuttering dyslexia autism and intellectual disability Emphasis is placed on recent studies as well as descriptions of the author's personal research which will provide a promising new direction for future research on these issues In this text Asenova presents four separate studies aiming to examine hemispheric asymmetries in neurodevelopmental disorders These include the subtypes of developmental stuttering the subtypes of developmental dyslexia mild non syndromic intellectual disability with comorbid speech and language deficits and autism spectrum disorder with comorbid severe language impairment The use of uniform research methods including dichotic verbal perception tasks and lateral preference performance tests has led to findings that suggest that this new approach could be a key factor in overcoming the ambiguity of findings from previous studies By focusing on the discussion of key issues concerning the role of atypical laterality in the genesis of neurodevelopmental psychopathology in both past research and Asenova's own studies Brain Lateralization and Developmental Disorders is a valuable reading for students and researchers in neurodevelopmental psychopathology as well as in developmental neuropsychology and developmental neuroscience

Cognitive Neuroscience Society ... Annual Meeting Abstract Program Cognitive Neuroscience Society. Meeting, 2009

The Cognitive Neuroscience of Development Michelle de Haan, Mark H. Johnson, 2005-08-18 Provides an extensive overview of the methods used to study these questions and the emerging interface between neurobiological and psychological perspectives in the study of typical and atypical cognitive development

*Music Interventions for Neurodevelopmental Disorders* Alessandro Antonietti, Barbara Colombo, Braelyn R. DeRocher, 2018-08-10 This book explores how music can improve skills that are impaired in some neurodevelopmental disorders including ADHD attention deficit hyperactivity disorder autism and Rett syndrome Rehabilitation interventions based on the use of music termed music therapy are relatively widespread but not all are supported by empirical evidence This book offers readers an



updated and scientifically grounded perspective on this theory and argues that music can be effective in promoting the acquisition of some basic mental abilities Chapters present some of the latest research and data on how musical activities can lead children affected by neurodevelopmental disorders to improve those skills including examples of training programs and exercises The book will be a valuable resource for therapists rehabilitators psychologists educators musicians researchers as well as anyone interested in exploring the potential in music for human growth      Neurodevelopmental Disorders Bin Chen, Kenneth Y. Kwan, 2020-05-24 Neurodevelopmental Disorders the latest release in the Comprehensive Developmental Neuroscience series presents the most thorough coverage available addressing all aspects on how the nervous system and its components develop This book brings together the latest research in this rapidly evolving field with section editors discussing the technological advances that are enabling the pursuit of new research on brain development This volume focuses on neurodevelopmental disorders in humans and experimental organisms Particular attention is paid to the effects of abnormal development and on new psychiatric neurological treatments being developed based on our increased understanding of developmental mechanisms Features leading experts in various subfields as section editors and article authors Presents articles that have been peer reviewed to ensure accuracy thoroughness and scholarship Covers disorders of the nervous system that arise through defects in neural development      **Human Behavior, Learning, and the Developing Brain** Donna Coch, Geraldine Dawson, Kurt W. Fischer, 2010-06-15 Thoroughly examining brain behavior relationships in atypically developing children this important volume integrates theories and data from multiple disciplines Leading authorities present research on specific clinical problems including autism Williams syndrome learning and language disabilities ADHD and issues facing infants of diabetic mothers In addition the effects of social stress and maltreatment on brain development and behavior are reviewed Demonstrating the uses of cutting edge methods from developmental neuroscience developmental psychology and cognitive science the contributors emphasize the implications of their findings for real world educational and clinical practices Illustrations include eight pages in full color This book will be important reading for practitioners and researchers in developmental and cognitive neuroscience neuropsychology developmental psychology clinical psychology education and psychiatry also of interest to advanced students It will also serve as a text in graduate level courses on learning and the brain developmental and cognitive neuroscience neurodevelopmental disorders and related topics      **Encyclopedia of Cognitive Science** Lynn Nadel, 2003 Reviews the themes information information processing representation and computation psychology philosophy linguistics computer science neuroscience education economics evolutionary biology anthropology

Neurodevelopmental Disorders Developmental Cognitive Neuroscience: Bestsellers in 2023 The year 2023 has witnessed a noteworthy surge in literary brilliance, with numerous captivating novels captivating the hearts of readers worldwide. Lets delve into the realm of bestselling books, exploring the fascinating narratives that have charmed audiences this year. The Must-Read : Colleen Hoover's "It Ends with Us" This touching tale of love, loss, and resilience has captivated readers with its raw and emotional exploration of domestic abuse. Hoover masterfully weaves a story of hope and healing, reminding us that even in the darkest of times, the human spirit can triumph. Uncover the Best : Taylor Jenkins Reids "The Seven Husbands of Evelyn Hugo" This captivating historical fiction novel unravels the life of Evelyn Hugo, a Hollywood icon who defies expectations and societal norms to pursue her dreams. Reids captivating storytelling and compelling characters transport readers to a bygone era, immersing them in a world of glamour, ambition, and self-discovery. Neurodevelopmental Disorders Developmental Cognitive Neuroscience : Delia Owens "Where the Crawdads Sing" This captivating coming-of-age story follows Kya Clark, a young woman who grows up alone in the marshes of North Carolina. Owens spins a tale of resilience, survival, and the transformative power of nature, captivating readers with its evocative prose and mesmerizing setting. These popular novels represent just a fraction of the literary treasures that have emerged in 2023. Whether you seek tales of romance, adventure, or personal growth, the world of literature offers an abundance of engaging stories waiting to be discovered. The novel begins with Richard Papen, a bright but troubled young man, arriving at Hampden College. Richard is immediately drawn to the group of students who call themselves the Classics Club. The club is led by Henry Winter, a brilliant and charismatic young man. Henry is obsessed with Greek mythology and philosophy, and he quickly draws Richard into his world. The other members of the Classics Club are equally as fascinating. Bunny Corcoran is a wealthy and spoiled young man who is always looking for a good time. Charles Tavis is a quiet and reserved young man who is deeply in love with Henry. Camilla Macaulay is a beautiful and intelligent young woman who is drawn to the power and danger of the Classics Club. The students are all deeply in love with Morrow, and they are willing to do anything to please him. Morrow is a complex and mysterious figure, and he seems to be manipulating the students for his own purposes. As the students become more involved with Morrow, they begin to commit increasingly dangerous acts. The Secret History is a brilliant and suspenseful novel that will keep you guessing until the very end. The novel is a cautionary tale about the dangers of obsession and the power of evil.

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