Flavour is arguably the most fascinating aspect of eating and drinking. It utilises a complex variety of senses and processes, that incredibly work together to generate a unified, and hopefully pleasurable, experience. The processes involved are not just those involved in tasting at the time of eating, but also memory and learning processes — we obviously shun those foods of which we have a negative memory, and favour those we enjoy. Our understanding of the science of flavour has improved in recent years, benefiting psychology, cuisine, food science, oenology, and dietetics. This book describes what is known about the psychology and biology of flavour. The book is divided into two parts. The first explores what we know about the flavour system; including the role of learning and memory in flavour perception and hedonics; the way in which all the senses that contribute to flavour interact, and our ability to perceive flavour as a whole and as a series of parts. The later chapters examine a range of theoretical issues concerning the flavour system. This includes a look at multisensory processing, and the way in which the mind and brain bind information from discrete sensory systems. It also examines the broader implications of studying flavour for societal problems such as obesity.
Recent neurophysiological studies have highlighted the dramatic integrative capacity of multisensory neurons and networks in response to stimulus combinations. In comparison to this rapidly expanding wealth of data on adult multisensory circuits, substantially less has been written about how multisensory neurons and their associated networks develop during early life. However, this situation is quickly changing as the developmental chronology of multisensory processes is mapped in both subcortical and cortical brain structures. These studies have revealed that multisensory neurons appear rather late in development, and initially lack the striking integrative characteristics that define their adult counterparts. As postnatal life progresses, however, the incidence of multisensory neurons increases rapidly and their non-linear integrative capabilities start to appear. Sensory experience appears to play a major role in shaping these developmental events, in that animals raised in environments devoid of multisensory associations or with altered associations develop abnormal integrative features.

Multisensory Control of Movement
Alain Berthoz (ed.)

Published in print: 1993 Published Online: March 2012
Publisher: Oxford University Press DOI: 10.1093/doi:10.1093/acprof:oso/9780198547853.001.0001

Truly international, this extensive text combines the efforts of eight laboratories from seven countries in investigating the study of problems of manipulation, orienting, and navigating in humans and animals. The multidisciplinary approach places the study of multisensory control of movement in a three-dimensional frame, with reference to computer models and neuronal mechanisms.

Multisensory Development
Andrew J. Bremner, David J. Lewkowicz, and Charles Spence (eds)

Published in print: 2012 Published Online: September 2012
Publisher: Oxford University Press DOI: 10.1093/doi:10.1093/acprof:oso/9780199586059.001.0001

Our daily perceptual experiences are, almost without exception, multisensory. We perceive the objects, events and people around us through a range of sensory modalities which convey overlapping and complementary streams of information about our environment and ourselves. A person’s face, the sound of their voice, the way they touch us, and even their distinctive smell, contribute to our perception, recognition and understanding of them. In the last two decades we have
witnessed dramatic progress in our understanding of how the mature adult brain integrates the information available to the different senses. However, despite the fact that adults are able to achieve multisensory integration in a seemingly effortless manner, developmental research has shown incontrovertibly that we cannot assume that the same is true for individuals who are at different stages of development, or who have had differing degrees or qualities of multisensory experience. This volume brings together the most recent research programmes from leading developmental scientists who have used a variety of methods to investigate questions concerning multisensory development. The various chapters address the development of a diverse range of cognitive and behavioural functions including classic questions about the multisensory perception of objects, people, language, but also issues which are just beginning to be addressed in detail, such as the development of multisensory interactions in flavour perception spatial navigation, and body representation. Crucially, this volume also tackles questions about how multisensory development comes about. This is achieved through a consideration of developmental processes throughout, and also through coverage of development across a wide range of groups.

The multisensory approach to development
Andrew J. Bremner, David J. Lewkowicz, and Charles Spence

in Multisensory Development

Published in print: 2012 Published Online: September 2012
Publisher: Oxford University Press DOI: 10.1093/acprof:oso/9780199586059.003.0001
Item type: chapter

Philosophers and psychologists alike have debated for centuries how humans and other species deal with the multiple sources of sensory information that specify the world around them. Recent years have seen a dramatic increase in our understanding of multisensory processes in mature adults, which have led to the conclusion that multisensory processes are ubiquitous in mature psychological functioning. However, developmental research has also shown that multisensory integration takes time to develop and that early experience plays a key role in its development. This chapter describes how the development of multisensory functioning can both constrain and enrich perceptual and cognitive functioning through the lifespan. This chapter also reflects on the history of the field, and draws out some key themes of recent research in multisensory development.
The development and decline of multisensory flavour perception
Charles Spence

in Multisensory Development

Published in print: 2012 Published Online: September 2012

This chapter reviews the evidence concerning the development and decline of multisensory flavour perception. The emphasis is on the role of visual cues, especially colour. Taken together, the available research suggests that the influence of visual cues on multisensory flavour perception decline during the course of childhood, and increases once again in old age. The latter developmental change is presumably driven by the decline of gustation and olfaction increasingly seen in people who live past the age of 60–70 years. Limitations with the interpretation of previous studies are highlighted and numerous suggestions for future research made. The tricky question of whether vision’s influence on multisensory flavour perception is best conceptualized in terms of multisensory integration or expectation effects is also discussed.

The development of multisensory balance, locomotion, orientation, and navigation
Marko Nardini and Dorothy Cowie

in Multisensory Development

Published in print: 2012 Published Online: September 2012

This chapter reviews the development of multisensory control of whole-body movement. The developing interactions between non-visual (e.g. vestibular and proprioceptive) and visual (e.g. optic flow) sensory inputs for whole-body control are discussed. Even very young children use multisensory information for spatial orienting responses, and to control balance and locomotion. In many tasks, research shows that visual information is heavily weighted in infancy and early childhood, but is gradually down-weighted during development in favour of somatosensory and vestibular inputs. Sensory integration for more complex navigation tasks shows an extended developmental trajectory. The application of Bayesian (ideal observer) models to understanding sensory integration and re-weighting in childhood is discussed.
The unexpected effects of experience on the development of multisensory perception in primates

David J. Lewkowicz

in Multisensory Development

Published in print: 2012 Published Online: September 2012
Item type: chapter

This chapter reviews what is currently known about the development of audiovisual perception in infancy and shows that the ability to perceive multisensory coherence takes time to emerge. In addition, recent findings are reviewed that show for the first time that experience contributes in an unexpected, but critical, way to the emergence of multisensory perceptual skills in human infants and developing monkeys. These data demonstrate that young infants are broadly tuned to multisensory inputs and that, as a result, they treat audiovisual inputs as coherent regardless of whether they represent a native or a non-native species or a native or nonnative language. Furthermore, these findings indicate that multisensory perceptual tuning narrows during the first year of life and that, as it does, the ability to perceive multisensory coherence of non-native signals declines. Finally, these findings suggest that multisensory perceptual narrowing may be a recent evolutionary phenomenon because young vervet monkey infants do not exhibit narrowing and, thus, continue to perceive the coherence of the faces and vocalizations of another species.

The development of audiovisual speech perception

Salvador Soto-Faraco, Marco Calabresi, Jordi Navarra, Janet F. Werker, and David J. Lewkowicz

in Multisensory Development

Published in print: 2012 Published Online: September 2012
Item type: chapter

This chapter considers the contribution of multisensory processes to the development of speech perception. Evidence for matching and integration of audiovisual speech information within the first few months of life suggests an early preparedness for extracting multisensory relations in spoken language. Nonetheless, it is currently not known what relative contribution speech-specific vs. domain-general abilities make to this early appearing ability. Brain mechanisms supporting audiovisual
speech processing also seem to be functional very early on, although they are relatively rudimentary compared to such mechanisms in adults. Together, these findings suggest that the development of audiovisual speech processing is neither strictly incremental nor linear. This is illustrated by evidence of age- and experience-related modulations including perceptual narrowing, strengthening of audiovisual integration by middle childhood, the influence of linguistic context, and plastic adaptation following declines in sensory acuity.

**Multisensory processes in old age**

Paul J. Laurienti and Christina E. Hugenschmidt

in Multisensory Development

Aging is an important stage of development accompanied by changes in all five sensory systems, and recent research indicates that aging influences multisensory processing, as well. This chapter reviews the current literature on aging and crossmodal interactions. There are now several reports of increased multisensory integration with advancing age, although evidence is now starting to accumulate that the probability of integration may decrease. Potential neurobiological reasons for these changes are discussed, first by addressing the bottom-up mechanisms that determine the likelihood of integration, such as space and time, and then examining the potential for changes in top-down functions like attention to alter multisensory interactions. Lastly, the importance of baseline sensory functioning to interaction of the senses is addressed.

**Developmental disorders and multisensory perception**

Elisabeth L. Hill, Laura Crane, and Andrew J. Bremner

in Multisensory Development

This chapter presents a review of research concerning multisensory processing impairments in three developmental disorders: developmental coordination disorder (DCD), autism spectrum disorder (ASD), and developmental dyslexia (DD). By comparing multisensory processes across these three disorders, a number of similarities in
sensory responses were noted (e.g., hypo- and hyper-sensitivity to sensory information, sensorimotor impairments). This chapter discusses whether multisensory processing abnormalities could represent a particular vulnerability or, perhaps more importantly, a particular risk factor in atypical development. Within and across disorders, possible developmental trajectories that may have led to such impairments are examined. Finally, the need for further multisensory research in developmental disorders is highlighted, and avenues for future research explored.

Generative Probabilistic Modeling: Understanding Causal Sensorimotor Integration

Sethu Vijayakumar, Timothy Hospedales, and Adrian Haith

in Sensory Cue Integration

Published in print: 2011 Published Online: September 2012
DOI: 10.1093/acprof:oso/9780195387247.003.0004
Item type: chapter

This chapter argues that many aspects of human perception are best explained by adopting a modeling approach in which experimental subjects are assumed to possess a full generative probabilistic model of the task they are faced with, and that they use this model to make inferences about their environment and act optimally given the information available to them. It applies this generative modeling framework in two diverse settings—concurrent sensory and motor adaptation, and multisensory oddity detection—and shows, in both cases, that the data are best described by a full generative modeling approach.

Humans' Multisensory Perception, from Integration to Segregation, Follows Bayesian Inference

Ladan Shams and Ulrik Beierholm

in Sensory Cue Integration

Published in print: 2011 Published Online: September 2012
DOI: 10.1093/acprof:oso/9780195387247.003.0013
Item type: chapter

This chapter first discusses experimental findings showing that multisensory perception encompasses a spectrum of phenomena ranging from full integration (or fusion), to partial integration, to complete segregation. Next, it describes two Bayesian causal-inference models that can account for the entire range of combinations of two
or more sensory cues. It shows that one of these models, which is a hierarchical Bayesian model, is a special form of the other one (which is a nonhierarchical model). It then compares the predictions of these models with human data in multiple experiments and shows that Bayesian causal-inference models can account for the human data remarkably well. Finally, a study is presented that investigates the stability of priors in the face of drastic change in sensory conditions.

Self-Motion Perception: Multisensory Integration in Extrastriate Visual Cortex
Christopher R. Fetsch, Yong Gu, Gregory C. DeAngelis, and Dora E. Angelaki

in Sensory Cue Integration
Published in print: 2011 Published Online: September 2012
DOI: 10.1093/acprof:oso/9780195387247.003.0016

The accurate perception of self-motion is essential for spatial orientation, navigation, and motor planning. Estimating our instantaneous direction of translation, or heading, is a particularly relevant multisensory problem because it requires cross-modal integration even under ordinary conditions. This chapter discusses how heading perception is a useful model for studying the neural basis of multisensory integration for two main reasons. First, there are well-defined brain structures that receive both visual and vestibular signals related to self-motion (e.g., macaque areas MSTd and VIP). Second, the problem is amenable to study using a standard “fine” psychophysical discrimination task, for which there are already well-established behavioral and neurophysiological analysis methods.

A Neural Implementation of Optimal Cue Integration
Wei Ji Ma, Jeff Beck, and Alexandre Pouget

in Sensory Cue Integration
Published in print: 2011 Published Online: September 2012
DOI: 10.1093/acprof:oso/9780195387247.003.0021

This chapter lays out a theoretical framework for how optimal cue integration can be implemented by neural populations. The main significance of this framework does not merely lie in understanding multisensory perception in a principled manner, but in the fact that it provides a blueprint for finding neural implementations of other forms of
Bayes-optimal computation. Evidence for Bayesian optimality of human behavior has been found in many perceptual tasks, including decision making, visual search, oddity detection, and multiple-trajectory tracking. Probabilistic population coding provides a roadmap for identifying a neural implementation of each of these computations: First the Bayesian model at the behavioral level needs to be worked out, then it needs to be assumed that probability distributions in this model are encoded in neural populations with Poisson-like variability, and finally the neural operations that map onto the desired operations on probability distributions should be identified.

The chemical senses
Jay A. Gottfried, Dana M. Small, and David H. Zald

in The Orbitofrontal Cortex

The orbitofrontal cortex (OFC) is described as secondary olfactory and gustatory cortex. This chapter reviews the location of chemosensory processing in the OFC as defined by anatomical and neurophysiological methods in nonhuman primates, and neuroimaging and lesion data in humans. The human neuroimaging data suggest that broader areas of the OFC are involved in chemosensory processing than would be predicted from a strict anatomical analysis of input from primary olfactory/gustatory cortex. The properties of chemosensory processing in the OFC are discussed in terms of the breadth of tuning of sensory cells, the role of hedonics, and the dynamic nature of coding (response to satiety). Issues of functional lateralization and medial vs. lateral distinctions in hedonic processing are also covered. Finally, topics related to multisensory integration are covered.

The role of olfaction in human multisensory development
Benoist Schaal and Karine Durand

in Multisensory Development

Olfaction is an unavoidable and ubiquitous source of perceptual experience from the earliest stages of mammalian development. This
chapter summarizes current understanding of how olfaction functions in concert with the other senses during human development, and the various ways early multisensory effects involving the chemical senses operate. This chapter first summarises aspects of current biological and psychological knowledge concerning olfaction in humans in order to provide some functional principles useful to understand the development of chemosensation in the context of multisensory processes. Finally, the available results concerning odour-based intersensory effects are reviewed.

Crossmodal interactions in the human newborn
Arlette Streri
in Multisensory Development
Published in print: 2012 Published Online: September 2012
DOI: 10.1093/acprof:oso/9780199586059.003.0004
Item type: chapter

Newborns are largely naïve when they enter the world. How can they make sense of the wealth of stable or moving objects, events, and people that they encounter through audition, vision, touch and olfaction? This chapter focuses on the various perceptual mechanisms and crossmodal interactions that exist in newborns. Some crossmodal interactions, such as chemosensory interactions, stem from the prenatal life of the newborn; while others, such as auditory-visual and tactile-visual interactions, only emerge at birth. These interactions present different complexities and levels of processing. Crossmodal interactions observed in human newborns involving the chemical senses, audition, and vision are discussed first. Then, the relations between the visual and the tactile modalities in newborns are examined in detail. These relations shed light on an old philosophical question: Molyneux’s famous question (July, 7, 1688) and the origin of crossmodal identity.

The development of multisensory representations of the body and of the space around the body
Andrew J. Bremner, Nicholas P. Holmes, and Charles Spence
in Multisensory Development
Published in print: 2012 Published Online: September 2012
DOI: 10.1093/acprof:oso/9780199586059.003.0005
Item type: chapter
This chapter reviews research directed at tracking the development of multisensory representations of the body, limbs, and the near-to-hand environment in infancy and early childhood. The focus is on the development of the multisensory processes involved in the representation of the body in a canonical posture, and more dynamic forms of multisensory integration which are required to represent the body as it moves and adopts different postures. These kinds of representation form the basis of action on the environment. The chapter argues that an understanding of the development of multisensory representations of the body and peripersonal space has important implications both for theories of perceptual and cognitive development.

The role of intersensory redundancy in early perceptual, cognitive, and social development

Lorraine E. Bahrick and Robert Lickliter

in Multisensory Development

Published in print: 2012 Published Online: September 2012
Item type: chapter

The early development of attentional selectivity is thought to be strongly influenced by the infant’s sensitivity to salient properties of stimulation such as contrast, movement, intensity, and intersensory redundancy (overlapping information across auditory, visual, tactile and/or proprioceptive stimulation for properties of objects and events). In this chapter, the powerful role of intersensory redundancy in guiding and shaping early selective attention, and, in turn, perception and learning is explored. The recent empirical and theoretical efforts to better understand what guides the allocation of selective attention during early development are reviewed and the implications of early selective attention for perceptual, cognitive, and social development are briefly discussed.