COGNITIVE DEVELOPMENT
The Learning Brain

SAMPLE CHAPTER

Usha Goswami
Cognitive Development
Cognitive Development
The Learning Brain

Usha Goswami
University of Cambridge

Copyright © 2008 Psychology Press http://www.psypress.com/goswami/
For Roshan Lal Goswami
Contents

Acknowledgments ix
Foreword xi

1. Infancy: The physical world 1

2. Infancy: The physical world 2 40

3. Infancy: The psychological world 74

4. Conceptual development and the biological world 108

5. Language acquisition 146

6. The central role of causal reasoning 182

7. Social cognition, mental representation, and theory of mind 220

8. The development of memory 250

9. Metacognition, reasoning, and executive function 294

10. Reading and mathematical development 334

11. Theories of cognitive development 372

References 419
Author index 445
Subject index 453
Acknowledgments

I have greatly enjoyed re-writing *Cognition in Children* into the current book. The text was largely written in my office at St John’s College, Cambridge, which provided a haven from the constant interruptions that I experience when in my Faculty office. I would like to thank both St John’s College and the Faculty of Education for providing me with the intellectually stimulating environments that have informed the book. I would also like to thank Victoria Cheah and my secretary Nichola Daily for their willingness to chase down references and their work on the bibliography. Finally, I would like to thank all the lively students and contract researchers at the Centre for Neuroscience in Education for contributing to a really enjoyable working environment, and in particular my colleague and Lecturer in Neuroscience in Education, Denes Szűcs.

Usha Goswami
Cambridge, May 2007
Foreword

When does cognitive development begin? Traditionally, it has been assumed that cognitive development—the development of attention, learning, memory, reasoning, language and concepts—can only commence once the baby leaves the womb. Yet more recent studies show that the fetus exhibits learning, memory and volitional motor behaviour. In fact, fetuses have surprisingly active lives. Ultrasonic scanning studies reveal that, by the fifteenth gestational week, the fetus has at least 15 distinctly different movement patterns at its command, including a yawn-and-stretch pattern and a “stepping” movement that enables it to change its position in the womb (via rotation) within 2 seconds (de Vries, Visser, & Prechtl, 1984). Fetuses suck their thumbs by the fifteenth gestational week. This prenatal thumb-sucking predicts later handedness; babies who suck their right thumbs at 15 weeks become right-handed and most babies who suck their left thumbs at 15 weeks become left-handed (Hepper, Wells, & Lynch, 2004). Studies also show that fetuses have some form of cognitive life. Research has shown that memory for the mother’s voice is developed while the baby is in the womb (see Chapter 3), and there is also evidence for fetal learning of particular pieces of music (such as the theme tune of the soap opera Neighbours; Hepper, 1988). These responses seem to be mediated by the brainstem (Joseph, 2000). However, there is also cortical activity within the womb, for example there are functional hemispheric asymmetries in auditory evoked activity in the fetal cortex (Schluessner et al., 2004). The fetus also shows deceleration of heart rate to certain sounds while in the womb (thought to index attention) and habituation of heart rate to vibro-acoustic stimuli (thought to show rudimentary learning; see Hepper, 1992; Kisilevsky & Low, 1998).

COGNITIVE NEUROSCIENCE: A NEW ERA

The recent advances in cognitive neuroscience mean that a new era is dawning in terms of understanding cognition in children. Cognitive psychology explains cognition via concepts and ideas held in the mind: cognitive representations. These are assumed to be discrete and symbolic (“amodal”). Cognitive neuroscience enables the study of the groups or networks of neurons that are active in the brain when cognitive representations are active in the mind. In cognitive neuroscience, mental representation is studied directly, in terms of brain structure and function. Neural mental representations are distributed, because many neurons are active at once when a mental representation is activated, and these neurons may be in different parts of the brain. It is likely that a better neural understanding of mental representation will have consequences for our understanding of what cognitive representations are, and of how they develop.

Technical advances in brain scanning now enable us to create images of the active areas of the living brain at any point in time. This enables us to watch the brain...
at work as it solves a problem or as it makes a causal inference. At the time of writing, three neural imaging techniques are suitable for studying children. One is electroencephalography (EEG), which involves placing sensitive electrodes on the child’s scalp to record brain electrical activation. The electrodes measure the low-voltage changes caused by cells firing action potentials during cognitive activity. EEG is very time sensitive and can record changes in brain activity at the millisecond level. However, a drawback of the technique is that the signals it records are difficult to localize.

A second suitable measure is functional magnetic resonance imaging (fMRI), which measures changes in blood flow in the brain. An increase in blood flow to particular brain areas causes the distribution of water in the brain tissue to change. fMRI works by measuring the magnetic resonance signal generated by the protons of water molecules in neural cells, generating a BOLD (blood oxygenation level dependent) response. The BOLD response peaks over time, hence fMRI lacks the millisecond resolution of EEG. Images are typically acquired over 0.5 to several seconds. However, fMRI offers very good spatial resolution in terms of where in the brain neural activity is taking place.

Finally, a new technique that also enables the measurement of changes in blood flow is functional near-infrared spectroscopy (fNIRS). Changes in oxygen availability (blood oxygenation level) are also shown by changes in the quantity of haemoglobin in brain tissue. Near-infrared light is absorbed differentially by brain tissue depending on the concentration of haemoglobin. Hence if optodes emitting near-infrared light are placed at the electrode positions used in EEG, changes in blood volumes can be measured. fNIRS enables the collection of data with better spatial quality than EEG and better temporal quality than fMRI, without a child needing to lie inside a large and noisy cylindrical magnet (as in fMRI). However, fNIRS does not, at present, offer temporal accuracy comparable to EEG, nor spatial accuracy comparable to fMRI.

Currently, most neuroimaging studies are of adults, so we know most about how the developed system works during linguistic, perceptual or reasoning tasks. However, studies with children are increasing. We already know that most of the brain cells (neurons) that a child has form before birth, by the seventh month of gestation (see Johnson, 1997; Joseph, 2000; for overviews). Accordingly, the environment within the womb can affect later cognition. For example, certain poisons (e.g. excessive alcohol) have irreversible effects on brain development, which affect later mathematical cognition (see Kopera-Frye, Dehaene, & Streissguth, 1996). Knowledge about brain development also constrains certain kinds of theorizing in developmental psychology. An example is the notion of “critical periods” for cognitive development (which are a “neuromyth”; see Goswami, 2004, 2006). Although there are sensitive periods for developing certain types of mental representation (e.g. the representations for speech sounds; see Chapter 5), the brain retains plasticity throughout the lifespan. Knowledge about when and how different neural regions develop may also offer new insights into long-standing and intriguing developmental problems (such as why infants make the “A-not-B” search error; see Chapter 2).

After birth, brain development consists mainly of the growth of connections between neurons: synaptogenesis. This leads the infant brain to double in size during
the first year of life. Brain cells pass information to each other via low-voltage electrical signals, which travel from neuron to neuron via special junctions called synapses. As soon as the child is born, the brain is busy sculpting connections between neurons, proliferating some connections and pruning others. The main determinant of this sculpting is the environment experienced by the child. Environmental sculpting establishes specific neural pathways and networks, which will be the basis of perception, attention, learning, and memory. In general, primary sensory systems are established first (e.g. the visual and auditory systems, the motor system); higher-order association areas mature later (Casey, Galvan, & Hare, 2005). The prefrontal cortex is one of the last brain regions to mature. However, the environment does not have to be especially rich to promote optimal development. Rather, the brain is set to respond to normative visual and auditory experience. When many neurons in a network are “firing” together, the patterns of neural activity are thought to correspond to particular mental states or mental “representations”. Although few studies currently use neural imaging to understand how a cognitive representation for a concept such as “animate” or “inanimate” develops in a young child, in time this will become possible. Meanwhile, I will mention relevant cognitive neuroscience studies wherever possible when discussing cognition in children in this book.

**Two core developmental questions**

The study of cognition in children has traditionally focused around two major questions. The first is the apparently simple question of *what develops*. This question can be investigated by observing changes in children’s cognitive abilities over time. For example, we can define certain principles of logical thought (such as the Piagetian principles of conservation and transitivity; see Chapter 11) and then track the development of these principles over time with experimental tests. At a very simple level, we can investigate “what develops” by using cognitive neuroscience techniques. We know, for example, that the sensory-motor cortex (vision, audition, action) matures earlier than the language and spatial areas (temporal and parietal cortices), with the prefrontal cortex (reasoning, problem-solving, monitoring one’s cognitive behaviour) maturing last of all, during adolescence and early adulthood. Such observations suggest that visual and auditory behaviour will approximate adult levels earlier than reasoning behaviour or self-monitoring behaviour. Remarkably, Piaget’s theory of cognitive development began with a sensory-motor phase and ended with higher-order reasoning (see Chapter 11). In this sense, Piaget’s theoretical framework parallels the course of brain development.

Information about *what develops* provides data for the second major question in cognitive developmental psychology, the less simple question of *why* development pursues its observed course. This question requires us to develop causal explanations for observed cognitive changes. Traditionally, we try to understand why development pursues the course that it does via experiments. Most of this book will be concerned with such experiments. In the future, it may also be possible to develop causal explanations from neuroscience studies. For example, certain brain structures or certain chemical messengers (neurotransmitters, which pass information across the
synapse) may turn out to be important in explaining certain cognitive disorders. An example is schizophrenia, which may be caused in part by abnormal dopamine activity. According to one current theory, neonatal perturbation of the hippocampus disrupts the normal development of prefrontal cortex and its regulation by the neurotransmitter dopamine (see Lipska & Weinberger, 2002). The cognitive effects include heightened reactivity to stress and poor executive control. However, the environment exerts a strong effect on who will become schizophrenic as an adult. For example, Afro-Caribbean adults in the United Kingdom are between 2 and 18 times more likely to develop schizophrenia than genetically matched adults who still live in the Caribbean (Fearon & Morgan, 2006). Hence neurocognitive risk does not necessitate cognitive disorder. This illustrates the complexity of the interactions between brain, environment and cognition (see Munakata, Casey, & Diamond, 2004; Gottleib, 2007; for useful reviews). Neuroscience also offers the potential for new therapeutic interventions. For example, abnormalities in dopamine regulation might be improved by antipsychotic drugs that target dopamine metabolism. Although such drugs indeed improve schizophrenic symptoms, the causal mechanisms by which they exert their therapeutic actions are still very poorly understood (Winterer & Weinberger, 2004).

Two core explanatory systems

Traditionally, two alternative (although not mutually exclusive) explanatory systems have been developed to account for changes in children’s cognition. The first type of theoretical account is based on the idea that core modes of learning or reasoning are applied across all cognitive domains. This is a “domain-general” explanation of cognitive development. Whether a child is attempting to understand why another child is upset (the “domain” of psychological causation), why animals usually have babies that look like them (the “domain” of biology), or why objects fall when they are insufficiently supported (the “domain” of physical reasoning), domain-general accounts postulate that certain types of learning, such as causal learning, or certain types of reasoning, such as the ability to make deductive inferences, are applied to the acquisition of all of these understandings.

The second type of theoretical account postulates that the development of cognition is piecemeal, occurring at different time points in different domains. According to this view, cognitive development is “domain specific”. For example, deductive inferences may appear in the domain of physical causality long before they appear in the domain of psychological causality. The reason may be that a rich and principled understanding of the physical world is acquired before a rich and principled understanding of the psychological world (a “theory of mind”). Domain-specific accounts of cognitive development acknowledge the importance of the knowledge base in children’s cognition.

The knowledge that we have affects our cognition when we are adults as well as when we are children. While the ability to (for example) make deductive inferences per se might be a domain-general development, the use of deductive inferences may be domain specific. Children may need sufficient knowledge to use their deductive
abilities in different domains, just as adults do (most of us could not make valid
deductions in unfamiliar domains such as nuclear physics). This example illustrates
why the two explanatory systems developed to account for changes in children’s
cognition are not mutually exclusive. In this book, I will argue that certain types of
learning, such as statistical learning, learning by imitation, learning by analogy and
causal learning, are domain general. However, their use in different domains depends
partly on knowledge. Other factors may also affect the observed pattern of cognitive
development. These include the richness of the child’s environment, the maturation
of certain cognitive structures such as the frontal cortex, and the quality of the
support and teaching that a child receives at home and in school.

This book focuses on the question of “what develops” rather than on the question
of “why”. The findings from a given experimental study (“what develops”) are
generally fixed but the interpretation of what particular findings mean (“why”) is fluid.
This is one of the most exciting aspects of research. Some of the experiments that will
be discussed have alternative interpretations, and every student interested in children’s
cognition is invited to develop his or her own ideas about what the different studies
mean (preferably along with some ideas about how to find out whether the studies are
right or not!). My aim is to provide a selective, but hopefully representative, review of
some of the most interesting historic and current work in cognitive development. By
considering research on perception and attention, learning, language, conceptual
development, memory development and the development of logical, psychological and
causal reasoning, we will study the different kinds of knowledge that children acquire,
and how they acquire them. At the end of the book, we will assess the impact of recent
findings in developmental psychology on the most famous theories of cognitive
development, the theories of Jean Piaget and Lev Vygotsky.

**Learning and constraints on learning**

A central theme, which will become apparent in our discussion of “what develops”,
will provide a partial answer to the question of “why”. As we will see, the human
infant is born with certain kinds of learning mechanisms at its disposal. The infant
brain can learn statistical patterns in the environment, enabling the extraction of an
enormous amount of information. Infants are skilled at associative learning, for
example, they readily learn that certain events co-occur. They are also skilled at
learning conditional probabilities—that a certain event will reliably occur given that
a specific prior event has occurred. The infant brain can also learn by imitation.
Perception yields many examples of agents (e.g. parents, sisters and brothers) acting
on the world, and infants can imitate what agents do, which appears to help them to
represent and understand human action and its causes (social cognition). Infants can
also learn by analogy. Imitation may involve an early form of analogy, as infants
can recognize others as being “like me” (see Chapter 3). Finally, infants have an
impressive ability to learn about causal relations and to acquire causal explanations
(“explanation-based learning”; see Chapter 2). This “causal bias” may begin from
infants’ interest in agents, and bestows a tremendous amount of information upon the
infant and the young child. Language acquisition facilitates this further. Anyone with
a child of their own, or with a young sibling, is familiar with the constant tendency
of young children to ask for causal information (“Why is the sky blue?” “How does the telephone call know which house to go to?” “How come the moon is big and orange now but other times it’s little and white?”; see, for example, Hood & Bloom, 1979; Callanan & Oakes, 1992). This relentless questioning is not just a device that children employ to keep a conversation going. Instead, causal questions such as these have an important developmental function.

Children’s focus on causal information gives them the ability to explain, predict and eventually even to control events within their everyday worlds. As we will see during this book, this “causal bias” acts to organize early memory, it underlies conceptual development, it helps the child to understand the physical world, it helps to organize the social world of agents and their actions, and it acts as a pacesetter for logical thought. The kinds of objects and events that infants are prepared to link in a causal fashion appear to be constrained in certain ways. For example, some kinds of movement appear more likely to be assigned a biological cause than others (e.g., erratic, unpredictable motion to biological causes, predictable motion to man-made artifacts). Some of these constraints on causal learning are discussed in Chapter 6.

Deduction and induction

Furthermore, children’s causal questions demonstrate that abilities such as deductive reasoning are present from an early age. Here is an example of everyday deductive reasoning by a 4-year-old, taken from an interchange that took place at the child’s bedtime (from Callanan & Oakes, 1992, p. 221–222):

Child (age 4) to her mother: “Why does Daddy, James [older brother] and me have blue eyes, and you have green eyes?”

The mother tells the child she got her eyes from Daddy. Then says goodnight and leaves the room.

Child (calls her mother back 5 minutes later): “I like Pee Wee Herman [a comedian] and I have blue eyes. Daddy likes Pee Wee Herman and he has blue eyes. James likes Pee Wee Herman and he has blue eyes. If you liked Pee Wee Herman you could get blue eyes too”.

Mother tells the child that God gave her this colour and they couldn’t be changed.

Child: “Could you try to like Pee Wee Herman so we could see if your eyes turn blue?”

The logical deductions here are impressive. The little girl reasons that $X$ (liking Pee Wee Herman) implies $Y$ (having blue eyes) in three cases out of three, and that $X'$ (not liking Pee Wee Herman) implies $Y'$ (not having blue eyes) in one case out of one. This covariation information appears persuasive and so she forms a causal hypothesis (liking Pee Wee Herman determines eye colour). She then thinks of a way
to test her hypothesis via an intervention (change $X'$ into $X$, and see if $Y'$ changes to $Y$). This exchange incorporates the knowledge that causes and their effects should systematically covary, and illustrates that young children are capable of deductive logic and hypothesis testing—even at the tender age of 4!

Inductive reasoning can be shown to be present at even younger ages. When we make inferences that are not necessarily deductively valid (when we “go beyond the information given”), we are reasoning inductively. For example, we might make a generalization on the basis of a known example, or use an analogy. Conceptual development and categorization depend on inductive reasoning and analogy. For example, when children learn about the category “birds”, they may learn about one or two exemplars (e.g. the robins and sparrows in their back garden). However, they are happy to generalize properties like “lives in a nest” to other birds, such as magpies, that they may not have seen before. These generalizations are made on the basis of inductive reasoning. When new exemplars (like magpies) appear typical of a category (like birds), then it seems natural to make generalizations about properties of a typical category member to other category members. Very young children do this all the time as they learn about the world around them, as we will see in Chapter 4.

Making a causal deduction is an example of a mechanism that seems to be both domain general and domain specific. Children make causal inferences in different domains at different points in development, for example using causal inferences to learn about the physical world before they use causal inferences in the biological domain. However, physical knowledge develops earlier than biological knowledge partly because the world of objects and events becomes familiar to the young infant before the world of plants and animals. The ability to make causal inferences thus appears to be domain general, emerging at different times in different domains according to the growth of domain-specific knowledge.

**Innate vs. acquired accounts of cognition in children**

A related theoretical issue to that of domain-specific versus domain-general explanations of cognitive development is that of nature versus nurture. Should the underlying causes of development be explained in terms of a rich genetic endowment of complex behavioural abilities, or in terms of rich experience of the environment? The metaphor of the mind of the infant as a blank slate has long been discredited, and so the “nature versus nurture” debate may appear no longer relevant to developmental psychology. However, recent research demonstrating the relative sophistication of infant cognition has led to a renaissance of quasi-nativist views. Yet genes cannot determine cognitive structures. Aspects of physiological structure that are thought to be totally under genetic control, such as tooth decay, can be dramatically altered by the environment. We can virtually eliminate tooth decay by looking after our teeth properly; we use environmental interventions, like brushing and flossing our teeth. The same principles will apply to psychological development, where organism–environment interrelationships are ubiquitous. Gene expression is controlled by the environment, including the environments within cells and brain
tissue (epigenesis). Although genes contribute to neural structures, these structures become active before they are fully mature and this activity itself shapes development (“probabilistic epigenesis”; see Gottleib, 2007). Knowing whether a particular ability is present at or near birth does not help us to understand its developmental origin. Instead, it is a starting point for the investigation of causes and consequences. The real question for cognitive developmental psychology is how neural and genetic activity interact with the environment and with behaviour to produce development. We need to ask questions about how the characteristics and limitations of infant motor, sensory, perceptual, and cognitive functioning produce modes of responding to the environment that help to shape the development of mature cognitive functions.

One famous acquired account of children’s cognition was offered by Jean Piaget, who developed a constructivist account of cognitive development. For a long time, Piaget’s theoretical framework dominated the field of cognitive–developmental psychology. Piaget is usually characterized as describing cognitive development as a qualitative process, because his was a stage theory, involving the emergence of new modes of thinking as revolutions occurred in the structure of thought. Piaget argued for three major modes of thinking, the sensory-motor stage, during which cognition was based on action; the stage of concrete operations, during which cognition was fully detached from the concrete world and was characterized by hypothesis testing and scientific thought. The stage of concrete operations was preceded by a “pre-operational” stage, making four stages in all. Although Piaget’s theory no longer dominates cognitive developmental psychology, some of his ideas are once more highly topical. Recent work in cognitive neuroscience highlights the core role of action in mental representations (“embodied cognition”), making Piaget’s emphasis on sensory-motor cognition in infancy prescient in terms of explaining early cognitive development. Similarly, symbolic development (whereby cognition becomes detached from the external world) turns out to be quite protracted, and very important in representational terms (e.g. see Chapters 3, 5 and 7). Experiments showing the context-bound nature of human reasoning suggest that we never attain the ability to think purely in terms of formal operations (see Chapter 9). Another famous account of cognitive development was offered by Vygotsky, who focused more on the influences of culture and language. Both Vygotsky’s and Piaget’s theories are considered in detail in Chapter 11.

The field of cognitive developmental psychology is at a crossroads in terms of theoretical explanations and, at the time of writing, a deeper understanding of brain development looks certain to set the pace for new theoretical perspectives such as neuroconstructivism (see Chapter 11). My focus in this book will thus be on documenting what experiments in psychology tell us about children’s cognition, bringing in cognitive neuroscience studies of mental representations where possible. The early chapters in this book focus on cognitive development in the “foundational” domains of human thought: the domains of physics, psychology and biology. We will then consider language acquisition, causal reasoning, memory and logical
development. Once a clearer understanding is gained of what the brain learns during childhood cognition, a clearer understanding of the appropriate explanatory frameworks for the “why” of cognitive development should become possible. I will thus end the book by considering how the traditional explanatory frameworks offered by Piaget and Vygotsky can be integrated with the new biologically driven frameworks offered by cognitive neuroscience and connectionism.
## CONTENTS

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Memory</td>
<td>4</td>
</tr>
<tr>
<td>Perception and attention</td>
<td>10</td>
</tr>
<tr>
<td>The perceptual structure of the visual world</td>
<td>19</td>
</tr>
<tr>
<td>Cognitive neuroscience and object processing in infancy</td>
<td>33</td>
</tr>
<tr>
<td>Links between measures of early learning, memory, perception, and attention, and later intelligence</td>
<td>35</td>
</tr>
<tr>
<td>Summary</td>
<td>38</td>
</tr>
</tbody>
</table>
Infancy: The physical world

What kinds of knowledge are central to human cognitive development? One proposal is that knowledge about the physical world of objects and events; knowledge about social cognition, self, and agency; and knowledge about the kinds of things in the world, or conceptual knowledge, are the “foundational” domains for cognitive development (Wellman & Gelman, 1998). These domains could be described as naïve physics, naïve psychology, and naïve biology. Infants need to understand objects and the physical laws governing their interactions; they need to understand social cognition (to interpret and predict people’s behavior on the basis of psychological causation) and they need to understand about the kinds of “stuff” in the world (such as animate versus inanimate entities). Clearly, cognitive development in these foundational domains is also dependent on the development of perception, memory, attention, learning, and reasoning. Most areas of cognition involve all of these skills at once.

It was once thought that young infants, who are immobile and whose perceptual abilities are still developing, had very limited cognition. For example, about 50 years ago it was thought that infants did not develop a full object concept until around 18 months of age (Piaget, 1954; a full object concept was thought to require an understanding that objects are enduring entities that continue to exist when out of view). This assumption seems to be quite wrong. Recent work in perception demonstrates that a remarkable amount of information about the nature of objects is given simply by watching things happen in the world. This passively acquired perceptual information is probably the source of early cognitive development concerning objects and their interactions. It is rapidly supplemented by information gained through direct action. Much richer information becomes available when the infant becomes able to reach, grasp, sit, and move. Similarly, perceptual information is replete with cues that can facilitate the development of social cognition, and in cues that inform an understanding of the animate–inanimate distinction. The development of knowledge in each foundational domain will be considered in the following chapters. It is important to keep in mind, however, that these types of knowledge are not developing separately in the infant.

At least three types of learning also appear to be functioning from very early in development. One is associative learning. Babies appear to be able to make connections between events that are reliably associated, even while in the womb. Once outside the womb, they appear able to track statistical dependencies in the world, such as conditional probabilities between visual events or between sounds. This turns out to be a very powerful learning mechanism. The second type of learning that appears to be available early is learning by imitation. This may be particularly important for the development of social cognition. Learning by imitation is considered further in later chapters. Finally, infants appear able to connect causes and effects by using “explanation based” learning. This “causal bias” was discussed in the Foreword. The causal inferences made by infants provide an extremely

KEY TERMS

- **Naïve physics**: An intuitive understanding we have about objects in the physical world, e.g. that objects that are dropped will fall, solid objects cannot pass through other solid objects, etc.
- **Full object concept**: An understanding that objects are enduring entities that continue to exist when out of sight, or otherwise unavailable to our senses.
- **Associative learning**: The ability to make connections between events that are reliably associated.
powerful mechanism for learning about the world. Infants are not simply detecting causal regularities but appear to be constructing causal explanations for new phenomena on the basis of their prior knowledge. One mechanism that they use is learning by analogy. This fourth type of learning is considered further in later chapters.

MEMORY

Memory is a good place to begin to study infant perception and cognition. After all, without some form of memory infants would live in a constant world of the “here and now”. To remember, babies must learn what is familiar.

Memory for objects

Infant memory was originally investigated using rather mundane objects and events. For example, Bushnell, McCutcheon, Sinclair, and Tweedie (1984) studied infants’ memory for pictures of simple shapes such as red triangles and blue crosses, which were mounted on wooden paddles. The infants were aged 3 and 7 weeks. Memory for a simple stimulus such as a yellow circle was first developed by asking the infants’ mothers to present the stimulus daily for a 2-week period. The mothers were encouraged to show their babies the stimulus “actively” for two 15-minute sessions per day. The babies were then visited at home by an experimenter, who showed them the habituating stimulus and also a random selection of the other stimuli, varying color, shape, or color and shape. The aim was to test the infants’ memories for these different aspects of the stimuli. For example, to test color memory, the baby might be shown a red circle rather than a yellow circle. To test memory for shape, the baby might be shown a yellow square instead of a yellow circle, and so on. Bushnell et al. found that the infants retained information about every aspect of the stimuli that they had been shown—shape, color, and size.

Cornell (1979) used pictures of groups of such stimuli to study recognition memory in infants aged from 5 to 6 months. In addition to pictures of patterns of geometric forms (Figure 1.1), he also used photographs of human faces. The babies were first shown two identical pictures from Set 1 side-by-side, followed by two identical pictures from Set 2, followed by two identical pictures from Set 3 (the photographs of human faces), and were allowed to study each set for a period of up to 20 seconds. Two days later they were shown the pictures again, first in a brief “reminder” phase in which each previously studied picture was presented on its own, and then for a recognition phase in which the familiar picture from each set was paired with an unfamiliar picture from the same set. Recognition memory was assumed if the infants devoted more looking time to the novel picture in each pair.

Cornell found a novelty preference across all the sets of stimuli that he used. Even though 2 days had passed since the infants saw the pictures, they remembered those that were familiar and preferred to look at the novel pictures in the recognition phase of the experiment. Their recognition memory was not due to the brief reminder
cue, as a control group who received the “reminder” phase of the experiment without the initial study phase did not show a novelty response during the recognition test. Given that the stimuli were fairly abstract (except for the faces) and were presented for a relatively short period of time in the initial study phase, their retention over a 2-day period is good evidence for well-developed recognition memory in young infants.

**Working memory in infancy**

The capacity to retain information over short periods of time is often called “short-term memory” or “**working memory**”. An influential model of memory in adult cognition is Baddeley and Hitch’s (1974) model, which distinguishes a short-term from a long-term system. The short-term system, called working memory, is thought to enable the temporary maintenance of information while it is processed for further use (e.g. in reasoning or in learning). Working memory is thought to have both visuospatial and sound-based (phonological) subsystems, which maintain visual versus auditory information respectively.

Working memory abilities in babies have been studied by Rose and colleagues (Rose, Feldman, & Jankowski, 2001). Rose et al. measured how many items could be held in mind by infants as they developed, testing the same babies when they were aged 5, 7, and 12 months. The infants were shown colorful toy-like stimuli, in sets of one, two, three, or four items. Once a particular set had been presented, recognition
memory was tested by pairing each individual item with a novel item. Working memory capacity was measured by seeing how many objects the babies recognized as novel. For example, if a baby had been shown a set of four items but seemed to recognize only two of them in the subsequent novelty preference pairings, memory span was assumed to be two items. Primacy and recency effects were also studied: in adult working memory experiments, participants find it easier to remember the first item of a set (primacy) and also the last item (recency). The question was whether babies would show the same effects.

Rose et al. (2001) reported that memory span increased with age. When they were aged 5 and 7 months, rather few babies could hold three or four items in working memory simultaneously (only around 25% of the sample achieved this span). By 12 months, almost half of the babies had a working memory span of three or four items. Recency effects were found at all ages tested—the babies showed better recall for the final item in the set. Primacy effects were not reported but have been reported in 7-month-old infants by Cornell and Bergstrom (1983). Hence the working memory system of young infants appears to operate in a similar way to that of adults. Primacy and recency effects in adults are explained in terms of the extra cues to recall provided by being the first or the last item in the list.

Memory for events

Some striking studies carried out by Clifton and colleagues have shown that 6-month-olds can also retain memories for events, and do so over very long time periods. For example, in one of Clifton’s studies, 6½-month-olds were able to retain a memory of a single event that had occurred once until they were 2½ years of age (Perris, Myers, & Clifton, 1990).

Perris et al. (1990) demonstrated this by bringing some infants who had taken part in an experiment in their laboratory as 6-month-olds back to the laboratory at 2½ and retesting them. During the infancy experiment, the babies had been required to reach both in the dark and in the light for a Big Bird finger puppet that made a rattle noise (the experiment was about the localization of sounds). The reaching session had taken about 20 minutes. Two years later, the children were brought back to the same laboratory room and met the same female experimenter, who said that they would play some games. She showed them five plastic toys, including the Big Bird puppet, and asked which toy they thought would be part of the game. She then told them that Big Bird made a sound in the game, and asked them to guess which one it was out of a rattle noise, a bell, and a clicker. Finally, the children played a game in the dark, which was to reach accurately to one of five possible locations for the sounding puppet. After five uninstructed dark trials, during which no instructions about what to do were given, the children were given five more trials in which they were told to “catch the noisy Big Bird in the dark”. A group of control children who had not experienced the procedure as infants was also tested.

Perris et al. found that the experimental group showed little explicit recall of their experiences as infants. They were no more likely than the control group to select Big Bird as the toy who would be part of the game, or to choose the rattle noise over the bell and the clicker. However, they showed a clear degree of implicit recall, as measured by their behavior during the game in the dark. They were more likely to reach out towards the sound than the children in the control group in the first five trials, and they also reached more accurately. If they were given a reminder of their
Infancy: The physical world

early experience, by hearing the sound of the rattle for 3 seconds half an hour before
the test in the dark, then they were especially likely to show the reaching behavior.
Again, this was not true of the control group. Finally, the children who had
experienced the auditory localization task as infants were much less likely to become
distressed by the darkness during the testing than the children who had not
experienced the auditory localization task as infants. Nine of the latter children (out
of 16) asked to leave before completing the uninstructed trials, compared to only two
children in the experimental group. Children who had experienced reaching in the
dark as infants thus showed evidence of remembering that event two years later in a
number of different ways. Similar results were reported in a study by Myers, Clifton,
and Clarkson (1987), who showed that children who were almost 3 years old also
retained memories of the laboratory and the auditory localization testing procedures
that they had encountered as infants. These children had had 15–19 exposures to the
experimental procedures as infants, however, and so their memory is in some sense
less surprising than that demonstrated in the experiment by Perris et al. (1990).

Memory for causal events

Event memory can also be studied by teaching infants a causal contingency between
a response and a reward. This technique of using learned causal relationships
between the production of a response and the delivery of a reward was exploited by
Rovee-Collier and colleagues in some pioneering studies (e.g. Rovee-Collier,
Sullivan, Enright, Lucas, & Fagen, 1980). In these studies, the conditioned response
was kicking and the reward was the activation of an attractive mobile hanging
over the infant’s crib. The contingency was that kicking activated the mobile.
Activation of the mobile occurred via a ribbon that was tied to the infant’s ankle. As
kicking comes naturally to young infants, the kicking response is present whether the
mobile is there or not. The important point about Rovee-Collier’s paradigm is that
the infant must learn that kicking makes the mobile start to work. Memory for this
cause–effect relation was then measured by returning the infants to the same crib
after some time had passed and seeing how much they kicked in the presence of
the mobile.

In a typical experiment, the infant is visited at home (see Rovee-Collier &
Hayne, 1987, for a review). An attractive mobile is erected on the side of the crib and
a second empty mobile stand is also erected (Figure 1.2). The ribbon is first tied to
this empty stand, to measure the baseline kick rate in the absence of reinforcement
with the mobile. After approximately 3 minutes, the ribbon is attached to the correct
mobile stand, and the infant is allowed to kick for about 9 minutes for the reward of
activating the mobile. The ribbon is then moved back to the empty stand for a final
3-minute period. The difference in kick rate between this second 3-minute period and
the initial baseline period provides a measure of the infant’s short-term retention of
the contingency. The infant is then visited a second time some days after the original
learning phase and the ribbon is again tied to the empty stand. Long-term retention
of the cause–effect relation is measured by comparing kicking in the absence of
reinforcement during this second visit with the original baseline kick rate.

Rovee-Collier and colleagues have found that 3-month-old infants show little
forgetting of the mobile contingency over periods ranging from 2 to 8 days. By
14 days, however, forgetting of the contingency appears to be complete. Furthermore,
as the time between the learning and test periods increases, the infants forget
the specific details of the training mobile (its colors and shapes), and respond as strongly to a novel mobile as to the original. Twenty-four hours after learning, the infants remember the objects on the mobile and will not respond to mobiles containing more than one novel object. By 4 days, however, they will respond to a novel five-object mobile. This suggests that infants, like older children and adults, gradually forget the physical characteristics or attributes of what they have learned, retaining only the gist or the associations between specific attributes and the context of learning.

Interestingly, at the same time as memory for the mobile itself declines, memory for the surrounding context (e.g. the pattern on the crib bumper) becomes more important in reactivating the infant’s memory of the contingency. Infants show perfect retention of the contingency at 24 hours, whatever the pattern on the crib bumper. By 7 days, infants who have been trained with a distinctive crib bumper show apparently complete forgetting if they receive a different crib bumper at test, whereas infants who receive the distinctive crib bumper at test remember the contingency. The different cues on the crib bumper, such as its colors and the particular shapes in its pattern, appear to be forgotten at different rates (Rovee-Collier, Schechter, Shyi, & Shields, 1992). It is difficult to escape the conclusion that details of the learning context, such as details of the pattern on a distinctive crib bumper, are acting to cue recall.

If the crib bumper indeed provides an appropriate “reminder” cue for recall, then we can examine whether “forgotten” memories become accessible again when appropriate retrieval cues are provided. Rovee-Collier and colleagues have developed a reactivation paradigm to study this question. The retrieval cue that they have studied most intensively is a reminder of the mobile contingency, namely showing the infants the moving mobile for 3 minutes prior to measuring kick rate. During the reminder phase, the mobile is activated by a hidden experimenter pulling...
on the ribbon, and the infants are prevented from kicking by a special seat that also precludes “on-the-spot” learning. The infants are then retested in the crib procedure 24 hours after the reminding event. With a reminder, 3-month-old infants demonstrate completely intact memories for the mobile contingency 14 and 28 days after the training event. Two-month-old infants show excellent memories after a 14-day delay, but only a third of this age group show intact memory after 28 days. By 6 months of age, the retention period is at least 3 weeks (Rovee-Collier, 1993). Thus very young infants can develop long-term memories for causal events, and memory retrieval appears to be governed by the same cues that determine retrieval in adults.

Another way of examining infants’ long-term memory for causal events is to use delayed imitation, a technique pioneered by Meltzoff in his studies of learning (see Chapter 2). Mandler and McDonough (1995) used delayed imitation to examine 11-month-old infants’ retention of causal events over a 3-month period. The events were two-step action sequences, namely “make a rattle” (by pushing a button into a box with a slot), and “make a rocking horse” (by attaching a horse with magnetic feet to a magnetized rocker). Imitation of the events was measured on the following day (24-hour retention period), and three months later. On each occasion the infants were simply presented with the materials (the horse, the rocker) and were then observed. To check that the older infants were not simply more likely to discover the sequences without having seen them being modeled, a control group of 14-month-old infants was also given the materials at the 3-month follow-up.

Mandler and McDonough found that recall was good at both the 24-hour and the 3-month retention intervals, and that there was little forgetting over the 3-month period. By contrast, retention of noncausal events (e.g. “put a hat on the bunny and feed him a carrot”) was poorer than that of causal events at 24 hours, and nonexistent after the 3-month interval. Mandler argues that retaining causal relations provides one of the major ways of organizing material that is to be remembered in a coherent and meaningful fashion. The importance of causal relations for memory development is covered more fully in Chapter 8.

**Procedural vs. declarative memories?**

It is notable that all of the studies discussed above have measured infant event memory in terms of the infants’ behavior. Rovee-Collier measured the amount of kicking that was produced to the mobile, Mandler the number of action sequences that were reproduced with the props, and Clifton children’s reaching behavior in the auditory localization paradigm. This raises the question of whether these memories are somehow different in kind to the type of memory in which we bring some aspect of the past to conscious awareness (e.g. Mandler, 1990). Is infant memory an active remembrance of things past, or is it more akin to a conditioned response of the type studied in animals?

In fact, it is widely accepted in cognitive psychology that there are two types of memory system in humans. One is automatic in operation, and is not accessible to verbal report. This kind of memory is usually called implicit or procedural memory. The second involves bringing the past to mind, and thinking about it. This kind of memory is usually called explicit or declarative memory. Only the latter involves information that has been encoded in such a way as to be accessible to consciousness. Infants are generally assumed not to encode explicit or declarative

**KEY TERMS**

- **Delayed imitation**
  - Imitation of a previously seen behavior after a delay.
- **Implicit or procedural memory**
  - Memory that is not available to verbal report.
- **Explicit or declarative memory**
  - Memories for earlier experiences that can be readily brought to mind and thought about.
memories until they become verbally competent, a phenomenon that has been called “infantile amnesia”. This assumption is probably incorrect, and is discussed more fully in Chapter 8. The development of implicit and explicit memories is also discussed more fully in that chapter.

PERCEPTION AND ATTENTION

Learning and memory in infants and neonates would be impossible if infants lacked adequate perceptual skills and adequate attentional mechanisms. Although there are some important immaturities in the visual system at birth (see Atkinson & Braddick, 1989), recent research has shown that the perceptual abilities of babies are much more sophisticated than was once supposed. We have already seen that visual recognition memory emerges early, as defined by responsiveness to novelty. Attention is clearly a prerequisite if visual recognition memory is to function effectively.

Adequate attentional mechanisms appear to be available shortly after birth. However, it is not clear whether these mechanisms are under the infant’s volitional control. It can be very difficult to attract an infant’s attention, particularly to a stationary visual stimulus, as many infant experimenters will tell you! At one point it was believed that infants were passive in their selection of visual stimuli. The idea was that attention to certain stimuli was obligatory, and that visual “capture” by these stimuli controlled infant attention (e.g., Stechler & Latz, 1966). This view is no longer widely held. The visual world of the baby is an active one, characterized by a dynamic flow of perceptual events over which the babies themselves have no control. To deal with this dynamic flow of events, infants need to develop expectations of predictable visual events, around which they can then organize their behavior (Haith, Hazan & Goodman, 1988). Thus, one way to study when attentional mechanisms in infants come under volitional control is to study their expectations of visual events. The development of visual expectancies requires the volitional control of visual attention.

Attention in infancy

To find out whether babies as young as 3½ months of age can develop visual expectations, Haith and colleagues devised a paradigm that involved showing babies a series of stimuli to the left and to the right of their center of gaze. In Haith et al. (1988), the stimuli used included pictures of checkerboards and bull’s eyes, and schematic faces in different colors (the kind of stimuli used by Fantz, 1961, to examine visual perception in babies, see below). Sixty stimuli were used in all. Thirty of these were presented in a left–right alternating sequence, which was thus predictable, and the remaining 30 were presented in a random left–right order. The movements of the babies’ eyes were observed during both the predictable and the random presentation sequences. Haith et al. argued that, if the infants could detect the alternation rule governing the appearance of the predictable stimuli, then they should develop expectations of the left–right alternation and should make anticipatory eye movements to the location of the next slide; such eye movements should be less common during the random presentation sequences. This was exactly what happened. The infants showed more anticipatory fixations to the predictable (alternating) sequence than to the unpredictable (random) sequence of pictures, and
also showed enhanced reaction times, meaning that they were developing expectations for the visual events quite rapidly. This shows that, at least by the age of 3½ months, babies can control their own perceptual (attentional) activity.

Using a somewhat different task, Gilmore and Johnson (1995) have shown that, by the age of 6 months, infants can also control their visual attention over delays of at least 3–5 seconds. Gilmore and Johnson’s paradigm involved showing the infants an attractive geometric display presented center-screen, in order to encourage fixation at the center (Figure 1.3). Once the infants were reliably looking at the central fixation point, a blue triangle (the “cue stimulus”) was flashed briefly either to the left or to the right of the center. The screen then stayed dark for a set time period until two rotating, multicolored cogwheel shapes (which were highly attractive to the infant) appeared: one to the left and one to the right of center. The experimenters then scored whether the infants showed a preference for looking at the cued location during the delay period, prior to the onset of the cogwheel targets.

Gilmore and Johnson found strong preferences for the cued location at each of the three different time intervals that they studied, which were 0.6 seconds, 3 seconds, and 5 seconds. They argued that this showed that the infants were maintaining a representation of the spatial location of the cue, and were using it to plan their eye movements several seconds later. In a follow-up study, Gilmore and Johnson cued the eventual left or right location of the target stimulus by presenting different geometric displays at the central fixation point, and omitting the blue triangle. For example, if the center-screen stimulus was a pattern made up of four shifting light- and dark-blue circles, then the target would appear on the right 3 or 5 seconds later, whereas if the

![Figure 1.3](image_url)
center-screen stimulus was a pattern made up of small red and yellow squares spiraling around each other, then the target would appear on the left 3 or 5 seconds later. The infants quickly learned this contingency and again showed strong preferences to look to the cued location. Gilmore and Johnson argue that their expectation paradigm also shows the early operation of “working memory” in the infant.

**Visual preference and habituation**

The existence of visual preferences in infancy provides a useful index of infants’ perceptual abilities as well as of their attentional skills. Suppose that we want to discover whether an infant can make a simple visual discrimination between a cross and a circle. One way to find out is to show the infant a picture of a cross and a picture of a circle and to see which shape the infant prefers to look at. The existence of a preference would imply that the infant can distinguish between the different forms. The “visual preference technique” was first used by Fantz (1961, 1966), who found that 7-month-old infants showed no preference between a cross and a circle; instead, they looked at both shapes for an equal amount of time (Figure 1.4).

A “no preference” result in the visual preference paradigm is difficult to interpret. It could mean that the infants were unable to distinguish between the two shapes being tested. Alternatively, it could mean that they found both shapes equally interesting (or equally dull!) to look at. One way to find out whether

![FIGURE 1.4](http://www.psypress.com/goswami/)  
*Examples of the visual preference stimuli adapted from Fantz (1961) to study infant form perception, showing the average looking time for each stimulus.*

**KEY TERM**  
*Visual preference technique*  
Infants are shown pairs of stimuli and a preference for looking at one indicates the ability to discriminate between the two.

INTEREST IN FORM was proved by infants’ reactions to various pairs of patterns (left) presented together. (The small and large plain squares were used alternately.) The more complex pairs received the most attention, and within each of these pairs differential interest was based on pattern differences. These results are for 22 infants in 10 weekly tests.
infants can in fact distinguish two equally preferred visual stimuli is to use the **habituation paradigm**. This has now become one of the most widely used techniques in cognitive research with infants. Habituation is assumed to give the experimenter a way into the infants’ conceptual (cognitive) representations.

In simple habituation studies, the infant is shown one stimulus, such as a circle, on repeated occasions. Typically, the infant’s interest is at first caught by the novel stimulus and a lot of time is spent in looking at it. Following repeated exposures of the same stimulus, the infant’s looking time decreases. This is quite understandable—seeing the same old circle again and again is not that exciting. Once looking time to the stimulus has fallen to half of the initial level, the old stimulus is removed and a new stimulus—such as a cross—is introduced. This is a novel stimulus, so if infants can distinguish between the cross and the circle, renewed looking at the cross should be observed. Renewed looking to a novel stimulus is called “dishabituation”. When dishabituation occurs, we know that the cross is perceived as a novel stimulus, and this tells us that infants can distinguish between a cross and a circle.

Research with neonates by Slater and colleagues has shown that infants can indeed discriminate a cross from a circle (Slater, Morison, & Rose, 1983). In Slater et al.’s experiment, the cross and the circle were both presented during the dishabituation phase, thereby combining the habituation method with the preference technique. Slater et al. showed that when the cross and the circle were presented after habituation to the circle, then the cross was preferred. When the cross and the circle were presented after habituation to the cross, then the circle was preferred. As neonates in a habituation paradigm can distinguish a cross from a circle, we can conclude that the absence of a preference in 7-month-old infants in Fantz’s experiments did not arise out of an inability to distinguish between crosses and circles.

**Cross-modal perception**

The ability to match perceptual information across modalities (cross-modal perception) also appears to be present from early in life. Infants seem to be able to connect visual information with tactile information, and auditory information with visual information, from soon after birth.

**Linking vision and touch**

One of the most striking demonstrations of infants’ ability to make cross-modal connections between vision and touch comes from an experiment by Meltzoff and Borton (1979), who gave 1-month-old infants one of two dummies, which had different textures, to suck. The surface of one of the dummies was smooth, whereas the other had a nubbled surface (Figure 1.5). The infants were prevented from seeing the dummy when it was placed into their mouths, and so in the first phase of the experiment their experience of the dummy was purely tactile. In the second phase of the experiment, the infants were shown enlarged pictures of both dummies, and the experimenters measured which visual stimulus the infants preferred to look at. They found that the majority of the babies preferred to look at

**KEY TERM**

**Habituation paradigm**

Infants are presented a stimulus, usually visual or auditory, until it no longer attracts attention: recovery of attention to a new stimulus (dishabituation) indicates discrimination between familiar and new.

**FIGURE 1.5**

The two dummies used to study intermodal connections between vision and touch by Meltzoff and Borton (1979). Copyright © 1979 Macmillan Publishers Limited. Reprinted with permission.
the dummy that they had just been sucking: The babies who had sucked on the nubbed dummy looked most at this picture and the babies who had sucked on the smooth dummy looked most at this picture. This suggests an early understanding of cross-modal equivalence.

**Linking vision and audition**

Infants also appear to be able to make links between the auditory and visual modalities soon after birth. For example, Spelke (1976) showed 4-month-old infants simultaneous films of two rhythmic events: a woman playing “peek-a-boo” and a baton hitting a wooden block. At the same time, the soundtrack appropriate to one of the events was played from a loudspeaker located between the two screens. Spelke found that the infants preferred to look at the visual event that matched the auditory soundtrack. Again, this preference for *congruence* across modalities suggests an understanding of cross-modal equivalence. Dodd (1979) has found similar results in experiments that required infants to match voices to films of faces reading nursery rhymes. When the soundtrack was played “out of synch” with the mouth movements of the reader, the infants got fussy. They preferred to look at faces whose mouths were moving in time with the words in the story. Adults also get fussy when they experience this phenomenon—think of being in the cinema when the soundtrack is out of time with the film. Clearly, we have a strong perceptual preference for congruence across different perceptual modalities, and this preference is present from early in life.

**Organizing perceptual information into categories**

Habituation methods can also be used to study when babies realize that visually distinct objects belong in the same conceptual category. This paradigm varies the stimuli that the infant sees during the *habituation phase* of the experiment. This variation of exemplars during habituation requires the infants to *categorize* what they are being shown in some way in order to remember it. At test, we can present the infants with a new exemplar of the familiar category that they haven’t seen before, as well as a new exemplar from a contrasting category. If the infants have formed a representation of the familiar category then they should prefer to look at the exemplar from the new category, even though both items presented at test are novel stimuli.

Slater and Morison (1987; described in Slater, 1989) used this categorization technique with 3- and 5-month-old babies. During the habituation phase of their study, they showed the babies a variety of types of circle (or of squares, triangles or crosses; Figure 1.6). At test, they showed the “circle” babies a new exemplar of a circle, and an exemplar of another shape, such as a cross. The infants preferred to look at the novel shape (the cross). This suggests that the babies had formed a “prototype”, or generalized cognitive representation, of the familiar shape, to which they appeared to be comparing all subsequently presented stimuli.

The ability to categorize exemplars as similar is an important *cognitive* process. The categorization of exemplars as similar suggests that a generalized representation or *prototype* has been formed, to which subsequently presented stimuli can be compared. One idea prevalent in adult cognition is that the use of prototypes enables
an organism to store maximal information about the world with the minimum
cognitive effort (Rosch, 1978; see Chapter 4). If we were unable to impose categories
on the perceptual world then every percept, object or event that occurred would be
processed as if it were unique. This would produce an overwhelming amount of
information. The ability to organize incoming information into categories is thus
essential for cognitive activity. Habituation studies have used a variety of stimuli to
discover whether babies can form prototypes of objects.

For example, suppose that you showed a baby a number of pictures of different
stuffed animals. You might show a picture of a stuffed frog, a picture of a stuffed
donkey, a picture of a stuffed alligator, a picture of a stuffed bear and so on. Although
these exemplars would differ in numerous features, the infants might be able to
abstract a category like “stuffed animals” from seeing these different instances, in
which case they should eventually habituate to these changing exemplars. By the
time they saw their fifteenth stuffed animal, even if it was a novel stuffed octopus,
you might find the “stuffed animals” category rather too familiar and show
habituation of looking.

Cohen and Caputo (1978) carried out a habituation experiment that was very
similar to the one just described with three different groups of babies, all aged 7
months. The first group saw the same stuffed animal on each trial of the habituation
phase of the experiment, the second group saw a different stuffed animal on each trial
and the third group saw a set of totally unrelated objects (e.g. a toy car, a ball, a
stuffed animal, a telephone). At test, the infants were shown a novel stuffed animal
and a rattle. The first group showed dishabituation to both the novel stuffed
animal and the rattle. The second group showed dishabituation to the rattle only and
the third group (which in any case had shown little habituation) showed no
dishabituation. This pattern of results is shown in Figure 1.7. Cohen and Caputo
argued that the second group had abstracted a category of “stuffed animals”.

![Triangle Square Circle Cross](image-url)

**FIGURE 1.6**
The different exemplars of triangles, squares, circles, and crosses used during habituation by Slater and Morison. From Slater (1989). Copyright © 1989 Psychology Press.
To argue that the infants were abstracting a prototypical “stuffed animal” from all of these instances, we would need evidence that they were attending to the interrelations between the different features of each stuffed animal, rather than habituating to a single recurring feature, such as the eyes. If infants can code the perceptual structure of objects in terms of the correlational structure between different features, then this would be good evidence for conceptual representation on the basis of perceptual prototypes. In fact, Rosch (1978) has argued that humans divide the world into objects and categories on just such a correlational basis. Certain features in the world tend to co-occur, and this co-occurrence specifies natural categories such as trees, birds, flowers, and dogs (see also Chapter 4). For example, birds are distinguished from dogs partly because feathers and wings occur together, whereas fur and wings do not. According to Rosch, this process of noticing co-occurrences between sets of features results in a generalized representation of a prototypical bird, a prototypical dog, and so on, and it has been argued that these perceptual prototypes provide the basis for conceptual representation.

Younger and Cohen (1983) examined whether infants were able to attend to the interrelations between features as required by prototype theory. They designed a habituation study based on “cartoon animals” to study this question (Figure 1.8). The cartoon animals could vary in five attributes: shape of body, shape of tail, shape of feet, shape of ears, and shape of legs. There were three different forms of each attribute (e.g. the feet could be webbed feet, paws or hooves). During the habituation phase of the experiment, the babies were shown animals in which three critical features varied; two of them varied together, and the third did not. For example, long legs might always occur with short necks, but tails could be any shape. Following habituation, the babies were shown three different cartoon animals. One was an animal whose critical features maintained the correlation; the second was an animal whose critical features violated...
the correlation, and the third was an animal with completely different features. Younger and Cohen found that 10-month-old babies showed dishabituation to the second and third animals, but not to the first. This result suggested that the babies were sensitive to the relationship between the different critical features. They had formed a prototype of an animal with a short neck and long legs.

One way to test whether the infants really were coding the correlational structure between the different features is to show different infants different sets of correlations between features, and then see whether they form different prototypes. Younger (1985) devised an ingenious method to enable such a test. She reasoned that if babies were shown cartoon animals in which all possible lengths of necks and legs could co-occur, then they should form a prototype of the *average* animal. As the different features would be uncorrelated with each other, the infants should abstract a prototypical animal with an average-length neck and average-length legs. However, if they were shown animals in which neck and leg length covaried in two clusters, for example long legs and short necks and vice versa, then they should form two different prototypes. One would be of animals with long legs and short necks, and one of animals with short legs and long necks.

To test her hypothesis, Younger used cartoon animals whose leg and neck lengths could have one of five values (e.g. 1 = short and 5 = long). Infants in a *broad* condition saw animals in which all possible lengths co-occurred except for length 3 (the average value), and infants in a *narrow* condition saw animals in which short legs went with long necks (1,5), and vice versa. At test, Younger found that the infants in the broad group preferred to look at cartoon animals with either very short

---

**FIGURE 1.8**
Examples of the cartoon animals used by Younger and Cohen (1983). Reproduced with permission from Blackwell Publishing.

Copyright © 2008 Psychology Press http://www.psypress.com/goswami/
legs and very long necks, or very long legs and very short necks (Figure 1.9). By contrast, the infants in the narrow group preferred to look at cartoon animals whose legs and necks were of average length (3,3). This suggests that the infants in the broad group found the average familiar, even though they had never seen those particular attributes before. They had abstracted a prototypical animal with an average-length neck and average-length legs. The infants in the narrow group had formed two prototypes, and thus found the average animal novel. Younger (1990) went on to demonstrate that babies were also sensitive to correlational structure when stimuli were based on features taken from real animals (“natural kinds”).

The use of more natural categories and real features to study prototype formation is important, as the correlational structure of objects in the real world is quite complex. Recently, developmental psychologists have begun to study whether infants can form prototypes of natural kinds, such as cats, horses, zebras, and giraffes. This work is relevant to infant understanding of the core domain of biology, and is considered in Chapter 4.

Prototypes and statistical learning in infancy

Younger’s cartoon-animal experiments demonstrated that infants could code the correlational structure between the different features being manipulated by the experimenters. This suggests a form of statistical learning. In effect, the infants were learning about statistical patterns; they were learning which features co-occurred together. Recently, there has been an explosion of interest in infants’ ability to track statistical patterns, particularly in the auditory domain (this work is discussed in detail in Chapter 5). However, the same questions can be asked in the visual domain. If the ordering of certain objects in the visual world follows a pattern, will infants track this pattern and show dishabituation when it is violated? This question was studied by Johnson and colleagues, testing infants as young as 2 months of age.

Kirkham, Slemmer, and Johnson (2002) created a visual habituation task based on simple colored geometric shapes. These were presented as a continuous stream by a computer monitor, for example, the participating infants (who were aged 2, 5, and

---

**KEY TERMS**

**Prototype formation**
The formation of an internal prototypical or generalized representation of a class of stimuli.

**Statistical learning**
Using the regularities in input to learn which features co-occur together.
8 months of age) might see a blue cross for 1 second, followed by a yellow circle for 1 second, followed by a green triangle for 1 second, and so on. Visual attention to the stream of objects was maintained by having the objects “loom” at the infants (essentially this means that the objects increased in size from 4 to 24 cm in height during presentation). The order in which the shapes were seen by a particular infant was varied, so that certain pairs of objects always followed each other. For example, a blue cross might always be followed by a yellow circle. Hence the transitional probability that when a blue cross was on screen the next shape would be a yellow circle was 1.0. Each infant saw a stream of six shapes, with three pairings. This meant that the transitional probability of the next shape after the yellow circle was 0.33. For example, if this particular infant was also seeing the pairs “green triangle, turquoise square”, and “pink diamond, red octagon”, then the likelihood that the yellow circle would be followed by a green triangle was 0.33, the likelihood that it would be followed by a pink diamond was 0.33, and the likelihood that it would be followed by a blue cross was 0.33. The stream of shapes continued for up to 90 seconds per trial for the 2-month-olds, and for up to 60 seconds per trial for the older infants.

Following habituation to the stream of shapes, the infants saw six test displays. Half of these comprised the familiar sequence and half were a novel sequence of new orderings produced randomly by the computer. The only difference between the familiar and novel sequences lay in the transitional probabilities between the shapes. This ensured that any looking time differences at test would depend on the statistical structure governing the sequence.

Kirkham et al. (2002) found that all groups looked significantly longer at the novel sequence. The 2-month-olds were as good at detecting novelty as the older infants. As there was no a priori relationship between the geometric shapes to provide information for co-occurrence, Kirkham et al. argued that they had demonstrated a true sensitivity to transitional probabilities in very young infants. Again, we see that infants have an impressive ability to keep track of the statistical structure in the input (see also Fiser & Aslin, 2002). The visual input structure in this experiment is quite arbitrary. It is not supported by rudimentary conceptual relations such as “instance of a cartoon animal”. This experiment with geometric shapes suggests that infants are able to learn about environmental structure at a fairly abstract level. This facility for statistical learning is also found in other domains, such as the auditory domain (see Chapter 5). The ability to track conditional probabilities provides a very powerful domain-general learning mechanism for extracting structure from the physical world of objects. We can now ask: What about events in the physical world? Events can also have predictable structure. Is the visual world of the infant organized into both objects and events?

THE PERCEPTUAL STRUCTURE OF THE VISUAL WORLD

The evidence for prototype formation shows that infants can code the perceptual structure of objects in terms of the relationships (covariations) between different features of these objects. Further, we have seen that they can track conditional probabilities between objects that follow each other in particular sequences. However, if this ability to detect statistical structure was restricted to the static features of natural kinds and artifacts, then even though it would be very useful, its cognitive value would be relatively limited. The ability to detect regularities between
Events in the visual world are usually described by relations between objects (such as football collides with goalpost, child pushes truck). The ability to detect structural regularities in these relations would confer great cognitive power, as events in the visual world are frequently causal in nature.

The detection of regularities in causal relations like collide, push, and supports between different objects may be an important mechanism in knowledge representation and thus in cognitive development. These regularities can also be described in terms of classes of event, such as “occlusion”, “containment”, and “support” (see Mandler, 1992; Baillargeon, 2001, 2002). Similarly, other types of relations, such as spatial relations (above and below) and quantitative relations (more than and less than), may also be detected. One way of measuring infants’ ability to process and represent spatial, numerical, and causal relations is to introduce violations of typical regularities in the relations between objects, which then result in physically “impossible” events. This is known as the “violation of expectation paradigm”, and has been widely used to study infant cognition. For example, an object with no visible means of support can remain stationary in mid-air instead of falling to the ground. The experimental investigation of infants’ ability to detect such violations provides an important way of measuring their ability to process relations between events and to represent the causal structure of these relations.

Representing spatial relations

One way to test whether infants are sensitive to spatial relations is to use habituation. For example, if an infant is shown a variety of stimuli that are all exemplars of the same spatial relation, and if the infant shows habituation to these stimuli, then the infant must be sensitive to relational information. If the infant is then shown an example of a new spatial relation, dishabituation should occur. This method was used in an experiment by Quinn (1994), who familiarized 3-month-old infants to the spatial relations above and below. This was achieved by showing half of the infants repeated presentations of a black horizontal bar with a dot above it in four different positions, and half of the infants a black horizontal bar with a dot below it in four different positions. These patterns provided exemplars of the spatial relation above and the spatial relation below, respectively. At test, the infants were shown a novel exemplar of the familiar relation (a dot in a new position above or below the bar, depending on the habituation condition), and an exemplar of the unfamiliar relation (a dot on the other side of the bar). Both groups showed a visual preference for the unfamiliar relation. This finding suggests that infants can categorize perceptual structure on the basis of spatial relations.

Experiments based on the spatial relations between dots and lines might appear to provide rather impoverished tests of relational processing and representation. In fact, monkeys can categorize such relations too (e.g. Spinozzi, Lubrano, & Truppa, 2004). However, there is evidence that infants show the same abilities with far more complex stimuli. For example, Baillargeon and colleagues investigated whether infants of 5½ months realized that a tall rabbit should be partially visible when it passed behind a short wall. During the habituation phase of the experiment, the infants saw a display of a tall painted “wall” (Baillargeon & Graber, 1987). A rabbit appeared at one end of the wall, passed along behind it, and reappeared at the other end. This “habituating” rabbit could either be tall or short, but as both the tall and the
short rabbit were too small to be visible when they were behind the wall, the infants watched the rabbits disappear and reappear as they moved from left to right. At test, the mid-section of the wall was lowered. The wall now had two tall ends and a short middle (Figure 1.10). The short rabbit could still pass behind the entire length of the wall without being visible but the tall rabbit could not. The tall rabbit’s head would appear as it passed behind the middle section of the wall.

Both groups of infants then again watched the habituating rabbit (tall or short) passing behind the wall. In fact, they saw the same event to which they had been habituated. For the “small rabbit” group, the failure of the rabbit to appear in the mid-section of the apparatus was perfectly acceptable in terms of the spatial relations involved, and accordingly there was no dishabituation. For the “tall rabbit” group, the test event was not acceptable in terms of the spatial relations involved—in fact, it was physically impossible. The tall rabbit’s head should have appeared behind the mid-section of the wall, but it did not—just as in the habituating event. Baillargeon and Graber found that the babies in the “tall rabbit” group spent much longer staring at the experimental apparatus than the babies in the “short rabbit” group. The infants’ increased looking time at the nonappearance of the tall rabbit suggests that they had represented the spatial relations between the wall and the rabbit. Later work (Baillargeon & DeVos, 1991) has shown that 3½-month-old infants behave in the same way (this was demonstrated in a modified version of the experiment, which used a tall and a short carrot). Thus very young babies appear to be able to represent spatial relations such as relative height, at least in an occlusion paradigm.

Baillargeon and colleagues have also used habituation to measure infants’ memory for spatial locations. This is a strong test of representation, as the infants must retain the spatial relations defining location over time. In one experiment, Baillargeon and Graber (1988) showed infants a display that had two possible locations in which a toy could be placed, A and B. The two locations were marked by identical mats. As the infants watched the display, an attractive object was placed at location A (in fact, the object used was a plastic styrofoam cup with matches stuck into its sides, an object that the infants found far more visually interesting than the toys that were used when the experimenters tried to pilot the experiment!). Two screens were then slid in front of the two locations, hiding the mats. As the infants...
continued to watch the display, a hand wearing a silver glove and a bracelet of bells appeared and the fingers danced around—this was also visually interesting, and was designed to keep the infants attending to the display. The hand then reached behind the screen at location B, and retrieved the styrofoam cup.

Of course, this retrieval was an “impossible” event. Location B had been visibly empty when the screens slid in front of the mats, and the styrofoam cup should only have been retrievable at location A. Baillargeon and Graber argued that if the babies could remember the location of the object during the delay, then they would be perturbed at this event, and should show increased looking at the display. This was exactly what they found. The babies stared at the impossible retrieval and looked at the display for a long time. Increased looking time did not occur in a control event, which was a “possible” event. In this event, the hand retrieved the cup from behind the correct screen, and the infants were not particularly interested. The fact that their attention was caught only when the cup was retrieved from the wrong spatial location suggests that they were able to represent the location of the cup even when it was out of view. Baillargeon, DeVos, and Graber (1989) went on to demonstrate that 8-month-old infants could retain these spatial memories for up to 70 seconds: So “out of sight” is not necessarily “out of mind” for infants.

A different test of spatial learning and memory was devised by McKenzie, Day, and Ihsen (1984). They seated 6- to 8-month-old babies behind a kind of semi-circular “news desk” (Figure 1.11). The babies sat on their mothers’ laps in a central position (like a “newsreader”), enabling them to scan the entire desk. The shape of the desk meant that there were a number of different locations at which events could occur, both to the left and to the right of the babies. The location at which an event was about to occur was always marked by a white ball. The events were visually exciting to the babies—an adult appeared from behind the desk and began playing “peek-a-boo”.

McKenzie et al. found that the babies quickly learned to anticipate an event at the spatial location marked by the white ball. As the white ball could appear either
to the right or to the left of the midline, the babies could not have learned a specific motor response, such as turning their heads to the right. Instead, they were learning to predict the spatial location of the visual events by using the white ball. McKenzie et al. argued that this showed that babies did not always code spatial position in memory egocentrically, with respect to a motor response based on their own position in space. When given the appropriate opportunity, they could also code spatial location in memory allocentrically, with respect to a salient landmark such as the white ball. The representation of spatial relations in 8-month-olds thus involves landmark cues, just as it does in adults.

Representing occlusion relations

So far, we have considered evidence that babies can use the perceptual structure of events in the visual world as a basis for representing relational knowledge about space. However, perceptual events can also provide conceptual knowledge about the continued existence of objects when they are out of view. When an object is occluded by a second object, we as adults believe that it still exists. Even when one object totally occludes another, we assume that the hidden object continues to exist and to occupy the same location in space behind the occluder.

Babies seem to make similar assumptions about the existence of occluded objects. One of the most ingenious demonstrations of their belief in “object permanence” comes from an experiment by Baillargeon, Spelke, and Wasserman (1985). Baillargeon et al. habituated 5-month-old babies to a display in which a screen continually rotated through 180° towards and away from the baby, like a drawbridge (Figure 1.12). Following habituation, a box was placed in the path of the

---

**FIGURE 1.12**

screen at the far end of the apparatus. As the screen began its $180^\circ$ rotation it gradually occluded the box. When it reached $90^\circ$ the entire box was hidden from view. For babies who were shown a “possible event”, the screen continued to rotate until it had passed through $120^\circ$; at which point it came to rest, apparently having made contact with the box. For babies who were shown an “impossible event”, the screen continued to rotate until it had passed through the full $180^\circ$ rotation. In the physically “impossible” condition, the box had apparently caused no obstruction to the path of the screen’s movement. Although the $180^\circ$ rotation was the familiar (habituating) event, the babies in the impossible condition spent much longer staring at the experimental display than the babies in the possible condition (who were seeing a novel event). This finding suggests that the babies had represented the box as continuing to exist, even when it was occluded by the screen. They looked longer at the display when the screen passed through an apparently solid object.

In later work, Baillargeon has shown that babies as young as 3½ months of age look reliably longer when the screen passes through the box, particularly if they are “fast habituators” (Baillargeon, 1987a). She has also shown that infants can represent some of the physical and spatial properties of the occluded objects, such as whether an object is compressible or not (e.g. a sponge vs. a wooden block; Figure 1.13), and whether it is taller or shorter than the height of the screen (e.g. a wooden box measuring $20 \times 15 \times 4$ cm standing upright vs. lying flat; Baillargeon, 1987b).

**FIGURE 1.13**
These experiments suggest that not only can young infants represent the existence of hidden objects, they can also represent some of the specific properties of the objects that are hidden. They can then use these physical and spatial characteristics to make predictions about how the drawbridge should behave as it begins to rotate.

Despite the many variations of the “drawbridge” paradigm that Baillargeon has devised, her use of a rotating screen to demonstrate infants’ belief in object permanence has proved to be a controversial one. For example, it has been argued that the perceptual structure of events in the “drawbridge” paradigm leads the infants to form a strong expectation that the drawbridge should stop, an expectation that does not necessitate a representation of the occluded object. This criticism is weakened by the demonstration that infants’ expectations about the behavior of the drawbridge differ depending on the nature of the object that is hidden (e.g., Baillargeon, 1987b). Furthermore, the series of drawbridge studies that Baillargeon and colleagues have conducted is only one piece of evidence that babies represent hidden objects as continuing to exist. A different paradigm, also devised by Baillargeon (1986), tests the same understanding and does not seem vulnerable to an “expectation” criticism at all.

This paradigm was based on a toy car and a ramp. During the initial phase of the experiment, 6½-month-old infants were shown a display in which a toy car was poised at the top of a ramp. A track for the car ran down the ramp and along the base of the apparatus. When the infants were attending to the apparatus, the middle section of the track was hidden by lowering a screen, and the habituation phase of the experiment began. The car ran down the ramp, passed behind the screen and reappeared at the end of the apparatus. Following habituation to repeated presentations of this event, the screen was raised and a box was placed either on the car’s track, or behind it. The screen was then lowered again, hiding the box, and the car began its journey. The apparatus used is shown in Figure 1.14.

All the babies then saw exactly the same set of events as during the habituation phase of the experiment. For babies in the “possible” condition, the box was behind the track and out of the car’s path, and so the reappearance of the car was not
surprising. For babies in the “impossible” condition, however, the box was on the track, directly in the path of the car—and yet the car still reappeared in the familiar way! The babies in the impossible condition spent much longer staring at the apparatus than the babies in the possible condition. The only explanation was that they had represented the box as continuing to exist and as therefore blocking the car’s path, and so they were intrigued by the reappearance of the car. Baillargeon and DeVos (1991) later demonstrated that babies as young as 3½ months looked for a reliably longer time when the car reappeared despite the fact that a hidden object (a Mickey Mouse doll) was blocking its path.

This paradigm was subsequently used by Kotovsky and Baillargeon (1998) to investigate babies’ understanding of collision events more directly. They explored infants’ expectations in situations where a stationary object was hit by a moving object. The moving object was a cylinder that varied in size, and the stationary object was a bug on wheels. When the cylinder collided with the bug, it set the bug in motion. As adults, we would expect the distance traveled by the bug following this collision to depend on the size of the cylinder. Kotovsky and Baillargeon explored whether babies aged from 5½ months also expected there to be a proportional relation between the size of the cylinder and the distance traveled by the wheeled bug. During habituation trials, the infants were shown the ramp, and a stationary wheeled bug sitting at the bottom of the ramp on the track. No occluders were used. As the infants watched, a medium-sized cylinder ran down the ramp, collided with the bug and set it in motion. The bug ran half way along the track and then stopped. In the novel event, either a larger or a smaller cylinder was used. Both cylinders propelled the bug to the end of the track. While this was a possible event for the larger cylinder, it should have been impossible for the smaller cylinder. The size of the cylinder should have affected the bug’s trajectory. Kotovsky and Baillargeon (1998) found that 6½-month-old babies and 5½-month-old female babies looked reliably longer at the small cylinder event than at the large cylinder event. They argued that the babies were engaging in calibration-based reasoning about the size/distance relations in the perceptual display.

Another type of occlusion event has also been the focus of investigations by Baillargeon’s group. Hespos and Baillargeon (2001a, b) studied the looking behavior of babies when potential containers were used as occluders. For example, either a tall or a short container made of PVC piping was used to occlude a brightly colored cylindrical object with a knob on the top. The tall container completely concealed the object, with just the knob on the top remaining visible. However, the short container was only about half as high as the object. Hence the top half of the object should have remained visible behind this short occluder. In fact, via the surreptitious use of two objects, the visual events seen by the babies were the same. When the object was lowered behind the short occluder it also became completely hidden, apart from the knob on the top. Of course, this violated the expectation that the object could not become fully hidden by the short occluder. Hespos and Baillargeon (2001a, b) reported that babies as young as 4½ months looked reliably longer at the impossible event. They apparently realized that the height of an object relative to the height of an occluder will determine whether the object will be fully or only partly hidden behind the occluder.

**Representing support relations**

Another set of perceptual relations that are commonly encountered in the physical world are the relations involved in support. Adults are well aware that if they put a
mug of tea down on a table and the mug protrudes too far over the edge, then the mug will fall onto the floor. However, if only a small portion of the bottom surface of the mug is protruding over the edge of the table, then the mug will have adequate support and the tea can be drunk at leisure. Baillargeon, Needham, and DeVos (1992) investigated similar intuitions about support in young infants. They studied 6½-month-old infants’ expectations about when a box would fall off a platform.

In Baillargeon et al.’s experiment the infants were shown a box sitting at the left-hand end of a long platform, and then watched as the finger of a gloved hand pushed the box along the platform until part of it was suspended over the right-hand edge (Figure 1.15). For some infants, the pushing continued until 85% of the bottom surface of the box protruded over the platform, and for others the pushing stopped when 30% of the bottom surface of the box protruded over the platform. In a control condition, the same infants watched the box being pushed to the right-hand end of the platform, but the bottom surface of the box remained in full contact with the platform. The infants spent reliably longer looking at the apparatus in the 85% protrusion event than in the full-contact control event. This suggests that they expected the box to fall off the platform (the box was able to remain magically suspended in mid-air via a hidden hand). The infants in the 30% protrusion event looked equally during the protrusion event and the control event. Baillargeon et al. argued that the infants were able to judge how much contact was required between the box and the platform in order for the box to be stable.

Interestingly, younger infants (5½- to 6-month-olds) appeared unable to make such fine judgments about support. They looked equally at the 85% and 30% protrusion events compared to the full-contact control event. Baillargeon et al.’s
interpretation of this finding was that younger infants perceive *any* amount of contact between objects to be sufficient to ensure stability. They operate with a simpler causal rule that *no contact = object falls*, and *partial contact = object is supported*, even when the partial contact is very partial indeed. In fact, Baillargeon argues that much physical causal reasoning develops according to this all-or-none pattern (see Baillargeon, 2001, 2002). Infants begin with representations that capture the essence of physical events (e.g. contact vs. no contact) and then gradually develop more elaborate representations that identify variables that are relevant to the events’ outcomes (such as degree of support). Experience of the physical world has an important role to play in this developmental sequence. For example, at around 6 months of age most babies become “self-sitters”. They are able to sit up, with support, and for the first time they can be seated in high-chairs, etc. in front of tables, and can deposit objects on surfaces and watch them fall off. Baillargeon has suggested that these experiences help infants to refine their understanding of the cause–effect relations underlying support. The idea that specific *action experiences* of this kind help in the development of specific aspects of physical reasoning is discussed further in Chapter 2.

**Representing containment relations**

Another way of investigating what Spelke (1994) has termed the “continuity principle”—that objects exist continuously in time and space—is to explore infants’ understanding of containment events. When an object is placed inside a container, it leaves the field of view. However, as adults, we know that the object continues to exist inside the container. Do babies share this understanding? In a series of experiments, Baillargeon, Luo, Wang, Paterson, and Hespos studied infants’ understanding of containment events (e.g. Hespos & Baillargeon, 2001a, b, 2006; Luo & Baillargeon, 2005; Wang, Baillargeon, & Paterson, 2005). For example, Hespos and Baillargeon (2001a) designed a containment study that was analogous to the occlusion study with the cylindrical object discussed earlier. The container was a piece of PVC tubing identical in perceptual appearance to the PVC tubing occluder. During the containment events, the infants watched as the cylindrical object was lowered inside the container (rather than behind the occluder). This comparison is shown in Figure 1.16. The tall container was large enough to contain the entire object, leaving just the knob on the top visible to the infants; however, the short container was not. In this condition, the top half of the object should have remained visible when it was lowered into the container. Instead, the object disappeared until only the knob was visible, violating expectations based on object continuity. Both the tall and the short container appeared able to contain the entire cylindrical object.

Intriguingly, Hespos and Baillargeon (2001a) reported that infants did not show increased looking times for the short container event until around 7½ months of age. They did not appear to realize that the height of the container relative to the height of the object determined whether the object would be fully or only partially hidden by the container. This was surprising, as infants aged 4½ months were able to use the relative heights of the object versus the container as a cue in the highly similar occlusion condition. In the containment condition, infants of 4½ months, 5½ months, and 6½ months of age did not appear aware of the importance of the height of the container. They did not look reliably longer at the short container event. Baillargeon
Infancy: The physical world

and Wang (2002) suggested that infants treated containment events as distinct from occlusion events. They did not generalize their knowledge of a variable like height from one type of event to the other.

In a separate series of studies, Luo and Baillargeon (2005) studied infants’ understanding of transparent containers. The infants were shown a plexiglass box, which was then occluded by a screen. An attractive object was then lowered into the box, although its entry into the box occurred out of view of the infant. When the screen was lowered, the infants either saw the object inside the box (possible event), or the empty transparent container (impossible event). Infants did not look for reliably longer at the empty container until 10 months of age. However, if the plexiglass was used as an occluder, rather than as a container (via a plexiglass screen), then infants from 7½ months of age looked longer at the physical violation. Again, this difference in looking behavior was interpreted in terms of event categories.

FIGURE 1.16
Familiarization and test events in the container condition of Hespos and Baillargeon’s (2001b) study. Reproduced with permission from Blackwell Publishing.
Infants were apparently treating containment events as distinct from occlusion events, and were working out the perceptual variables relevant to a more elaborate representation of occlusion events earlier than they were working out the perceptual variables relevant to a more elaborate representation of containment events—even when these were the same perceptual variables.

Apparent support for this interpretation based on event categories came from a separate series of studies comparing containment with covering. When a cover is lowered over an object, the same principle of continuity applies as when an object is lowered inside a container. The object continues to exist beneath the cover or beneath the container, and various physical attributes of the object or the cover/container will determine whether any parts of the object remain visible. Wang, Baillargeon, and Paterson (2005) used identical tubes as covers or as containers. For example, in one experiment 9-month-old infants watched as a tall tube was used to cover a tall object (Figure 1.17), or as a tall object was lowered into a tall cylindrical container. These were possible events. In the impossible events, the tall object was covered by a short tube or was lowered into a short cylindrical container. In all of the events, the object became fully hidden. Wang et al. reported that the infants looked reliably longer at the unexpected event in the containment condition, but not in the covering condition. Only infants aged 12 months detected the violation in the covering condition; 11-month-old infants did not. Again, these discrepancies in behavior were explained in terms of event categories. Covering seemed to be treated by infants as an event distinct to containment. Therefore, identical variables (such as tube height) were treated as relevant to one event category before they were treated as relevant to another. The explanation was that infants were sorting physical events into categories, and were learning separately how each category operated.

Although all the experiments discussed so far have used looking behavior in the violation of expectation paradigm as the outcome measure, more recently Baillargeon and colleagues have been testing this model of physical reasoning in infancy by using action-based tasks. For example, Hespos and Baillargeon (2006) exploited search behavior to compare infant actions in containment versus occlusion.
events. They studied the ages at which infants would search consistently for a toy that was either hidden behind an occluder or that was hidden inside a container. The occluders and containers were the same PVC tubes used in previous experiments. This time, infants were given an engaging tall frog toy to play with. The frog was then removed. The infants were shown a screen and, when the screen was lowered, two containers or occluders were revealed—one tall and one short. Frog legs were sticking out of the bottom of each, and the infants were encouraged to find the frog; 6-month-olds and 7½-month-olds were tested.

Based on their findings in the violation of expectation paradigm, Hespos and Baillargeon reasoned that infants identify the variable height as relevant at about 4½ months in occlusion paradigms and at about 7½ months in containment paradigms. They therefore argued that the younger infants should search for the frog behind the tall occluder in the occlusion paradigm, but should not preferentially search inside the tall container in the containment paradigm. The older infants were expected to search for the frog successfully in both paradigms. This was exactly what they found. In the occlusion condition, 12/16 7½-month-olds and 14/18 6-month-olds reached for the tall occluder on three or four of the four search trials. In the containment condition, only the older infants were successful, with 12/16 reliably picking the tall container compared to only 2/18 of the younger infants. Different control conditions were used to rule out alternative explanations. Hespos and Baillargeon (2006) concluded that evidence from action tasks was consistent with evidence from the violation of expectation paradigm concerning physical reasoning in infants. Physical reasoning by infants depends on the formation of distinct event categories (occlusion, containment, support), and infants learn about each category separately. Perceptual variables that are identified in one category may not be generalized to another category, even when they are equally relevant. Hespos and Baillargeon suggested that infants’ physical reasoning systems are designed to acquire event-specific expectations rather than event-general principles. This suggestion is consistent with what we know about the neural mechanisms of conceptual learning, as is discussed in Chapter 4.

What is measured in the violation of expectation paradigm?

Recently, a number of criticisms have appeared of studies that use habituation, visual preference, and violation-of-expectation techniques to study cognitive processes in infancy. Some of these critics are highly resistant to the notion that young infants engage in physical reasoning at all (e.g. Haith, 1998). Critics such as Haith point out—correctly—that looking paradigms were developed to study sensory and perceptual questions, not cognitive questions. We saw some examples of these perceptual questions at the beginning of this chapter. An important part of these critiques is the observation that it is simply not possible to generate perceptually identical but conceptually distinct stimuli for habituation paradigms (see Sirois & Mareschal, 2002, although note that this does not mean that looking time as a measure must be abandoned; see Aslin, 2007). Critics such as Haith argue that scientists like Baillargeon must be able to discount every possible perceptual interpretation of differences in looking time before proposing cognitive interpretations of infant looking behavior. In a similar vein, Bogartz, Shinskey, and Speaker (1997) argued that simple perceptual mechanisms such as novelty, scanning, and tracking...
may explain longer looking times by infants in some perceptual conditions versus others. These points are important: It is not clear that behavioral experiments will ever be able to devise conditions that unambiguously demonstrate cognitive representations in infants.

In fact, a theoretical point frequently made by such critics regards what it means to attribute cognitive representations to infants at all. For example, Haith (1998) suggests that infants may have lingering sensory information about objects that have been (for example) occluded, and that it is this lingering sensory information, rather than a conceptual representation of the object, that yields the changes in looking behavior. Perceptual mechanisms such as familiarity, novelty, and discrepancy, which operate when objects are visible, may also be operating to create longer looking times to “impossible” events simply because infants are still operating on actual sensory information, albeit degraded information. Haith points out that degraded sensory information is not a cognitive representation in the sense of a recomputation and transformation of sensory information into an (amodal) cognitive entity. He refers to neuroscience work in monkeys that enables the recording of brain activity from single cells, which shows that some of the same neurons that are active when an object is present are also active when it is absent. In other words, there is reduced sensory activity in the same perceptual systems that are active when a real object is present, even though the object has gone from the visual field. Haith suggests that this activity could constitute a neural mechanism for degraded sensory representations.

More recently, work in adult visual perception has shown that object representations in adults (“object files”, or mid-level visual mechanisms for treating part of the visual field as the same object over time) persist over several seconds (e.g. Noles, Scholl, & Mitroff, 2005). Object files in adults are also affected by violations of key principles of infant perception, such as cohesion (that an object must always maintain a single bounded contour; see Mitroff, Scholl, & Wynn, 2004). A more detailed exploration of how the visual system constructs and maintains object files may throw light on some of the curious discrepancies in infants’ use of perceptual variables such as height in the experimental paradigms devised by Baillargeon and colleagues.

However, regarding the question of degraded sensory representations versus amodal cognitive entities raised by Haith, more recent neuroscience work in human adults has superseded these arguments. Such work suggests that the distributed nature of mental representations means that there will always be activity by sensory neurons relevant to experiencing a concept when a cognitive representation is active (Barsalou, Simmons, Barbey, & Wilson, 2003). Concepts are represented in part by the reenactment of neuronal activity in primary sensory systems, and not by redescriptions of these states into an amodal representational form. Multiple representations appear to be involved when the human brain represents conceptual knowledge (see discussion in Chapter 4). If the brain is representing the concept of a cup, for example, motor neurons activated when the cup is grasped and visual neurons activated when seeing a real cup will become active, along with neurons in various association areas that might link cups to specific contexts like breakfast or specific emotions like the pleasure one gets from drinking coffee. There is no set of amodal “cup” neurons that is activated by themselves, without sensory activation. In fact, the new experimental techniques offered by cognitive neuroscience provide us with a way forward in tackling the serious questions about the nature of infant representations raised by scientists like Haith.
COGNITIVE NEUROSCIENCE AND OBJECT PROCESSING IN INFANCY

A series of experiments with 6-month-old infants reported by Kaufman, Csibra, and Johnson (2003a) provides a nice example of this potential way forward. Kaufman et al. used electroencephalogram (EEG) imaging as a way of examining what infants’ “representations” of occluded objects were actually like. As will be recalled, the EEG is a measure of brain electrical activation obtained by attaching sensitive electrodes to the scalp. The electrodes pick up electrical signaling by cell assemblies in the brain, although the exact generators of the signals are difficult to localize. Kaufman et al. recorded the EEG from electrodes placed over the whole scalp when infants were watching different disappearance events, which were either expected or unexpected. The habituation event was a toy train going into a toy tunnel. The train was shown entering the tunnel and then reversing back out again. Following habituation, the infants watched the train enter the tunnel, and then saw one of the following: (1) a hand lifting the tunnel to reveal the train (expected appearance event); (2) a hand lifting the tunnel to reveal no train (unexpected disappearance event); (3) the train leaving the tunnel and the visual field, and a hand subsequently lifting the tunnel to reveal the train (unexpected appearance event); or (4) the train leaving the tunnel and the visual field, and a hand subsequently lifting the tunnel to reveal no train (expected disappearance event). Behaviorally, the infants looked significantly longer at the unexpected disappearance event compared to the expected disappearance event. The two appearance events were not distinguished by looking time.

Kaufman et al. (2003a) then compared the EEG during the lifting of the tunnel in the expected versus unexpected disappearance events. Much higher electrical activity at temporal sites on the right side of the brain only was found when the train was occluded. In addition, when the tunnel was lifted to reveal no train (unexpected disappearance), there was sustained EEG activity, which peaked around 500 ms after the lifting of the tunnel. Kaufman et al. argued that this increased activity showed the brain attempting to maintain its representation of the train despite the competing visual evidence that the train was not under the tunnel. This higher activity could also represent the brain’s response to an unexpected event. However, Kaufman et al. argued that the fact that higher activity during object occlusion occurred only in right temporal electrodes ruled out a general explanation of brain activity based on degraded sensory input. It is not clear why degraded sensory representations should be maintained on one side of the brain and not on the other, or why they should involve increased neuronal activity.

To investigate further whether the sustained EEG activity shown when the tunnel was lifted was related to the representation of nonvisible objects, a second experiment was conducted using only appearance events. As will be recalled, behaviorally, the infants did not distinguish between expected and unexpected appearance in terms of increased looking time. As in the first EEG experiment, it was found that occlusion of the train led to increased EEG activity in the right temporal electrodes during the period that the train should have continued to exist beneath the tunnel. However, there was no change in the EEG when the tunnel was lifted. As the train was always revealed in the appearance conditions, Kaufman et al. argued that there was no need to maintain a representation of the object independently of visual input. Further, as the unexpected appearance was unexpected, the higher activity found for unexpected disappearance was unlikely to represent the brain’s response to an unexpected event.

KEY TERM

EEG (electroencephalogram)
The recording from the scalp of brain electrical activity caused by the firing of neural networks.
Research on how the brain processes objects has also shown that visual objects are processed via two neural pathways (Ungerleider & Mishkin, 1982; Milner & Goodale, 1995). One pathway—the dorsal route—is used for spatial and temporal information and is thought to be important for processing information that might be needed to guide action; this is called the “where” pathway. The second pathway—the ventral route—is used for processing information that is useful for identifying unique objects, such as color information; this is called the “what” pathway. The ventral route is also used for processing information about faces. Both pathways appear to process information about the size and shape of objects. Recently, it has been argued that this partial separation of the neural processing of different visual features of the same objects needs to be taken into account when interpreting looking experiments with infants (e.g. Mareschal, Plunkett, & Harris, 1999; Mareschal & Johnson, 2003).

For example, it seems quite plausible that younger infants may be poor at integrating information that is processed separately in the dorsal and ventral pathways. This idea was tested in an ingenious experiment reported by Mareschal and Johnson (2003). They exploited the preference of the ventral route for faces and color by examining 4-month-old infants’ memory for surface features of objects versus the spatial location of objects in an occlusion paradigm. The infants were habituated to five repetitions of two objects appearing sequentially from behind two occluders on a computer display. In each trial, the infants watched as one object moved out from behind the first occluder for 5 seconds, and then moved back behind it, to be followed by the second object moving out from behind the second occluder and returning behind it. In the test trials, the two occluders moved upwards to reveal the objects behind them. In the feature change condition, one of the objects (a face or a cartoon asterisk) changed color or identity. In the location change condition, the color of the cartoon asterisks or the identity of the faces remained constant but the location of each was switched. In parallel conditions using pictures of familiar graspable toys, either the identity of one of the toys was changed, or the location of the toys was switched. Faces and colored asterisks were selected because they were expected to be processed by the ventral route. In the parallel conditions, graspable toys were selected because they afforded the infant potential actions and hence should be processed by the dorsal route. In a final baseline condition, the occluders lifted to reveal the expected objects.

Mareschal and Johnson (2003) argued as follows: If 4-month-old infants have difficulties integrating object information processed by the ventral and dorsal pathways, then they should show increased looking time in the feature change condition when the objects were asterisks and faces, but they should show increased looking time in the location change condition when the objects were graspable toys. In each of these cases, one visual route can yield sufficient information for dishabituation. When infants had to process changes in the conjunction of features and location (e.g. when the object [toy] afforded action but changed in features rather than moving, or when the faces or colored asterisks preserved their features but changed location), looking time should not differ from baseline. Difficulties in integrating information from the two pathways would prevent the infants from keeping track of conjunctions.

This was exactly the pattern of results found. When the objects in the occlusion paradigm were faces or asterisks, the babies looked significantly longer in the feature change condition only. When the objects were graspable toys, however, the infants...
showed increased looking time in the location change condition only. They did not show dishabituation when the faces or colored asterisks moved location or when the graspable toys changed in appearance. This is a remarkable result, and illustrates the importance of understanding the neural processing that is underpinning infant looking behavior. As argued by Mareschal and Johnson (2003), it also has implications for the design of studies probing infants’ knowledge about objects. Depending on the kind of object used, infants may process features of that object differently. In particular, for real objects that can be grasped, location information appears to be retained at the expense of surface features like color. For objects that do not afford action, information about surface features is retained at the expense of information about location. This does not imply that infants cannot process changes in either surface features or location at the same time. Rather, there appears to be a selective loss of information when aspects of the object that are processed by the ventral stream must be integrated with aspects processed by the dorsal stream while an occlusion occurs.

Kaufman, Mareschal, and Johnson (2003b) have extended this argument to suggest that the potential graspability of the stimuli typically used in infant studies will influence how the infant brain will process these stimuli. They propose that the ventral/dorsal route framework can explain apparently conflicting results in the infant literature on object segregation, on the processing of surface features of moving objects, and on object individuation. Any experiments using small, familiar and moving objects as stimuli are likely to activate the dorsal route. Any experiments using larger, stationary objects are likely to be processed by the ventral route. Further evidence is needed to evaluate these ideas. For example, neuroimaging may be able to reveal a selective reliance on one route or another. At the moment, evidence of an inability to integrate information from both routes depends on a negative result (no difference in looking time compared to baseline). Negative results can have many causes. A direct measure of neural processing would be better evidence for this plausible hypothesis.

LINKS BETWEEN MEASURES OF EARLY LEARNING, MEMORY, PERCEPTION, AND ATTENTION, AND LATER INTELLIGENCE

A great many studies, only some of which have been mentioned here, provide converging evidence that the perceptual world of even the very young infant is organized into objects and their relationships. These relationships are organized in terms of events such as “containment” and “occlusion”. Most of our knowledge about infants’ cognitive representations of the physical world depends on experiments that exploit visual recognition memory, such as the visual preference technique and the visual habituation paradigm. One interesting question is whether there is continuity between these measures taken in infancy and later individual differences in cognitive development. Both measures reflect the basic information-processing capacity of an individual, involving learning, memory, perception, and attention. If early learning, memory, perception, and attention are related to later cognitive processing, then speed of habituation and visual recognition memory should be predictive of later individual differences in intelligence.
Speed of habituation and individual differences

The notion that there should be a relationship between the speed of habituation in infancy and later differences in intelligence has been proposed by a number of authors (e.g. Fagan 1984). Their argument goes something like this: A baby who is relatively quick to habituate to a stimulus might be relatively fast at processing information, and therefore capable of learning that something is familiar in only a few trials; such babies have been termed “short lookers” (see Rose, Feldman, & Jankowski, 2004). Another baby may take three times as long to habituate to the same stimulus, requiring many more trials to accurately and completely encode a stimulus in memory; such a baby would be a “long looker”. As a young child, this second baby may still be slower at processing information and will therefore be slower on a variety of cognitive tasks that contribute to standardized measures of intelligence. However, it is important to be clear that being a “fast looker” is not the same thing as having a low attention span. Children who are easily distracted and move quickly from one activity to another may have an “attention deficit disorder” (ADD), and ADD children usually under-perform in various intellectual tasks. These children are unlikely to be fast habituaters, although so far no-one has studied the connection between attention deficit disorder and habituation in infancy directly.

To examine whether individual differences in habituation are associated with later individual differences in intelligence, Bornstein and Sigman (1986) conducted a “meta-analysis” of available studies. This meta-analysis included studies that related decrements in attention (habituation or total fixation time) to later intelligence measures, and also studies that related recovery of attention (novelty preference and response to novelty) to later intelligence. They found that attention scores correlated on average 0.44 with follow-up studies of intelligence conducted at 2–3 years, 0.48 with follow-up studies conducted at 4–5 years, and 0.56 with follow-up studies conducted at 6 years or more. This suggests significant continuity between early habituation measures and later IQ.

One of the longest-running longitudinal studies of the relationship between speed of habituation and individual differences is that of Sigman and colleagues, who have been following the same cohort of children since they were born for over 12 years. For example, Sigman, Cohen, Beckwith, and Parmelee (1986) reported data from a group of 91 of the infants who were tested as neonates. These babies were tested again at 4 months, and were then followed up when they were 8 years old. Two-thirds of the group (N = 60) had English-speaking backgrounds and the rest came from varied language backgrounds (the study was conducted at a large hospital in California). As neonates, the infants were shown a single 2 × 2 checkerboard for three 1-minute trials, and at 4 months they were shown pairs of checkerboards of varying complexity (2 × 2, 6 × 6, 12 × 12, 24 × 24) for eight trials. Two measures of visual attention were taken: (1) a measure of total fixation time; and (2) a habituation measure of the percentage decrement in looking time across trials.

When the children were revisited as 8-year-olds, they were given the revised version of the Wechsler Intelligence Scale for Children (the WISC-R). This test measures IQ by combining performance scores on a number of verbal and nonverbal measures (e.g. verbal fluency, picture completion, block design, memory span). Sigman et al. found that the neonate measure of total fixation time predicted IQ at
8 years for the whole group, whereas the neonate habituation measure predicted IQ at 8 years for the children from varied language backgrounds only. The measures taken at 4 months did not add to the associations between the neonate measures and later IQ. Sigman et al. concluded that infants who spent a long time looking at the stimuli at 0 and 4 months performed less well on the intellectual assessments given in childhood. It seems as though infants who take a long time to process an unchanging stimulus as neonates are less intelligent later in life. Similar relationships were found when a smaller subgroup of the sample ($N = 67$) was seen again as 12-year-olds (Sigman, Cohen, Beckwith, Asarnow, & Parmelee, 1991). In addition, more efficient processing of stimuli as a neonate (looking for a shorter amount of time) was related to performance on a test of analogical reasoning at age 12 (e.g. bread is to food as water is to beverage).

**Visual recognition memory and individual differences**

Like habituation, visual recognition memory requires the infant to encode a stimulus, to recognize it as familiar, and to recognize an alternative stimulus as novel. These are all basic information-processing requirements that could be related to intelligence. Fagan (1984) used a visual preference paradigm similar to that of Cornell (1979) to test this hypothesis. He measured looking preference for a novel visual stimulus (a face) over an already-experienced visual stimulus (a different face of the same sex) in a group of 7-month-old babies, and then tested the same group when they were 3 and 5 years of age. The median amount of time that each infant spent looking at the novel stimulus rather than the familiar stimulus formed the dependent measure. Fagan found stable correlations of around 0.42 between the novelty preference measures taken at 7 months and performance on the PPVT (Peabody Picture Vocabulary Test, a measure of verbal ability) at 3 and 5 years. He argued that visual novelty preference measures in infancy are picking up something of *general* importance for later cognition, for example encoding abilities, the ability to detect invariant features or categorization abilities. Fagan’s idea that early visual recognition memory is a general rather than a specific measure has received support from a study by DiLalla et al. (1990). DiLalla et al. showed that Fagan’s novelty preference measure was a significant predictor of IQ at 3 years as measured by the Stanford–Binet intelligence test.

Another long-running longitudinal study of the relationship between visual recognition memory and individual differences in cognitive development also found a general relationship with broader cognitive abilities (see Rose et al., 2004, for a summary). Rose and Feldman (1995) studied the relationship between visual recognition memory in infancy and visual attention and later intelligence as measured by the WISC-R at 11 years of age. They also studied longitudinal relationships with language development, and measured Piagetian variables thought to provide a key index of cognitive development in infancy, for example object permanence. Rose and Feldman reported that the infancy measure that best predicted IQ at age 11 was visual recognition memory, with a correlation of 0.41. Ninety infants took part in the study, 50 of whom were preterm. The preterm infants were included as a group at risk (preterm infants tend to score on average about 10 points lower on later IQ tests than full-term infants). Rose and Feldman found
that the predictive strength of the visual recognition memory measure was very similar for both groups. In addition to overall IQ, infant visual recognition memory predicted performance on the Peabody Picture vocabulary measure at age 11, and predicted performance on particular subtests of the IQ tests used after controlling for overall IQ. These subtests were memory (measured via a speeded task) and perceptual speed. As Rose and Feldman point out, the relationship with perceptual speed may mean that processing speed is the common thread underlying cognitive continuity from infancy. For at-risk groups in particular, poorer performance can be tied to slower encoding of the target stimuli. Hence processing speed can play a limiting role in infant visual recognition memory. The importance of processing speed for cognitive development in general has also been highlighted by Anderson (1991) and by Kail (1991).

An alternative suggestion is that, rather than providing an index of information processing in terms of encoding, discrimination etc., both visual recognition memory and habituation derive their predictive power from their ability to provide an index of individual differences in the ability to inhibit responding to stimuli that have been seen before. Inhibition as an important cognitive process has received relatively little attention in the field of children’s cognition (e.g. Dempster, 1991; Houdé, 2000). However, it has been attracting increasing interest lately with the advent of cognitive neuroscience, which has revealed the importance of inhibition mechanisms in explaining cognitive performance, and also in linking biology to temperament and psychopathology (Fox, Henderson, Marshall, Nichols, & Ghera, 2005). Inhibition (and executive processes more generally) is discussed in Chapter 9.

**SUMMARY**

There is considerable continuity between measures of learning, memory, perception, and attention in infancy, and later individual differences in cognitive development. Babies as young as 3 weeks show learning and memory for simple objects, and 3-month-olds can learn causal contingencies and retrieve them 28 days later with appropriate retrieval cues. Six-month-olds can form event memories that can be retrieved 2 years later in the presence of the right reminders, and 6-month-old babies have working memories. Event memories seem to be procedural rather than declarative in nature, as both learning and memory are demonstrated via infant behavior. The relationship between such memories and bringing some aspect of the past to conscious awareness is discussed in Chapter 8.

Perceptual and attentional abilities are also impressive early in life. Neonates can discriminate between simple visual forms such as crosses and circles. Work with older infants suggests that the basis of these discriminations is fairly abstract perceptual information, as habituation also occurs to different exemplars of the same shape, novel exemplars being seen as familiar. Habituation at an abstract level suggests that rudimentary categorization is occurring, with babies forming a generalized conceptual representation or “prototype” of a particular visual form. Work on prototypes and sequential learning has shown an
impressive capacity for tracking conditional probabilities. This provides infants with a very powerful domain-general learning mechanism. In terms of learning about the physical world, it enables infants to construct a world of predictable objects that behave in predictable ways. Infants organize the physical world in terms of events like occlusion and containment. Once they become able to sit up and act on the world, they very quickly elaborate these early representations to encompass fine-grained knowledge about causes and their effects. This further development is discussed in Chapter 2.
Subject index

A–B–C paradigm 325–326
A-not-B error 69, 376
Abstract expectations 130–132
Accommodation 374, 375
Action experiences 28
Actions 81–87, 91–101, 245–246
Active quarantining 244–245
Agency 43, 44–45, 47–50, 72, 190, 193, 218
Alcohol consumption xii
Algebraic mind 404
Allophones 151, 340
Amodal neurons 32
Amygdala 245, 416
Analog magnitude representation 355–363, 370–371
Analogical mappings 144
Analogical reasoning 321–326
Analog xii, xiv, 134–135, 210–212, 377, see also Learning by analogy
Angular gyrus 160, 355
Animacy 44–46
Anterior cingulate 218, 245, 318
Antisaccades 319
Appearance-reality distinction 231, 236
Archimedes 321
Articulation rate 278–279
Assimilation 374
Association cortex 290, 291
Associative learning xv, 3
Attachment 77, 236–238
Attention 10–12, see also Joint attention
Attention deficit disorder 36
Attribution of mental states 102
Auditory information, cross-modal perception 14
Autism 50, 247, 290, 416
Autobiographical memory 267–269

Babbling 157–159
Balance scale task 206–208, 210–212
Basic-level categories 110–115
“Bear in the cup” paradigm 53
Belief desire psychology 226–228
Beliefs 110, 228–231, 242–243, 247, see also False belief
Benzene ring 321–322
Binary relations 387
Biological constraints 399–402
Biological movement 127–128
Biological/nonbiological distinction 126–138, 145

BOLD response xii
“Box on a platform” paradigm 27
Brain development xii–xiii
imaging xi–xii
Broca’s area 161
Bullying 241

Canonical babbling 157–158
Cardinal word principle 364
Cardinality 363
Categorical knowledge 138–141
Categorical perception 148–153
Categorization 14–16, 109–125
Causal agent 190, 193, 218
Causal Bayes nets 73, 184, 193–197, 408
Causal bias xv–xvi, 3–4
Causal chains 197–202
Causal directedness 188
Causal event memory 7–9
Causal expectations 131
Causal inferences 184, 185–188, 206–213, 408–409
Causal learning 52, 183
Causal mechanisms 184
Causal principles 184, 188–193
Causal reasoning 183–219
Causal relations 20, 42–43, 253–254
Causal strength 193
Causal structure 193
Causal transformations 185–188
Causality perception 42–43
Cause and effect 51, 185–188, 192–193
Central executive 274, 305
Centration 378
Characteristic features 140–141
Characteristic-to-defining shift 140
Chess expertise 287, 290
Child-basic categories 121–122
Child Language Checklist 163
CHILDES 176
Circular reactions 375–376
Class inclusion 378, 384–386
Coding of spatial position 23
Cognition, link with perception 41
Cognitive bridge 411
Cognitive concepts 50
Cognitive development theories 373–374
Cognitive flexibility 307–315

Cognitive representations 32, 376
Cognitive schemas 50
Cognitive self 256–257
Collective intentionality 224
Collision events 26, 43
Comfort sounds 157
Commission errors 272
Communication 179, 233–234, 235–236
Compositions 374
Comprehension precedes production 162–163
Concepts 32, 50, 109–110
Conceptual analysis 41–52, 72–73
Conceptual change 143–145
Conceptual development categorization 111
language 125–126
traditional view 109
Conceptual knowledge 109
Conceptual thought 376–377
Concrete knowledge 130–132
Concrete operational stage xviii, 374, 378–386
Concrete to abstract shift 140
Condition–outcome relationships 67
Conditional metacognitive knowledge 296
Conditional probabilities xv
Conditional reasoning 328–332
Confirmation bias 204
Congruence 14
Connectionist modeling 118, 145, 373, 402–407
Conservation 378, 380–384
Consistency problem 346–347
Consonant phonemes 149
Constraints on learning xv–xvi, 61, 109
Construction of memories 251
Containment relations 28–31
Contextual knowledge 193
Contingency learning 7, 77–80, 106, 410
Continuity principle 28
Contrastive outcomes 67
Conversation 179, 233–234, 235–236
“Cool” executive function 309
Core knowledge 66
Core properties 130–133

Copyright © 2008 Psychology Press http://www.psypress.com/goswami/
454  Subject index

Correspondences 322
Counting 363–370, 371
Covariation evidence 202–204, 217
Covariation principle 184, 188, 190–191
Crawling 70–72
Critical periods xii, 405
Cross-modal congruence 56–57
Cross-modal cues 46–47
Cross-modal perception 13–14
Crying 76, 157
Cultural semiotic systems 391
Cultural transmission 367, 371
Culture 389

Deaf
babbling 157–158
memory 277
mental representation 232–233
Declarative memory 9, 251, 290
Declarative metamemory 296, 297
Deductive logic 327–332
Deductive reasoning xvi, 320, 327–332, 333
Deferred imitation 62–64, 252
Defining features 140–141
Degraded sensory representations 32, 33
Delayed imitation 9
Delayed reaching 70
Descriptions 47
Desire-based psychology 225–228
Developmental dyslexia 349–351, 353–355, 401
Developmental primitive 183
Dimensional Change Card Sort (DCCS) task 307–309
Dinosaur experts 287–288
Discourse 233–247, 249
Dis-equilibrium 374
Dishabituation 13
Distributed mental representations 141
Distributed representations 403, 404
Dogs, word learning 171
Domain-general xiv, 51
Domain-specific xiv, 51
Dopamine system xiv
Dorsal stream 34–35, 59–61, 120
Dorsolateral prefrontal cortex 318, 319
Double dissociations 404
Drawbridge paradigm 23–25
Dual-route model of reading 401
Dyslexia 349–351, 353–355, 401
Early Social Communication
Scales 105
Ease-of-learning judgments 300
Education 392–395, 398
Egocentric speech 390

Egocentric thought 378
Embodied cognition xviii, 377, 407
Embodiment 400
Emergent theories 51
Entrainment 347
Ensocialment 400
Entrenchment 405
Environmental sculpting xiii
Episodic memory 251, 253–257, 264–269, 272–274, 292–293, 404
Epistemic function 414
Essentialism 141–143
Event categories 29–30
Event memory 6–9, 38
Event-related potentials (ERPs) 161, 291, 292, 361
Event schemas 50
Evidence 202–204
Executive function 230–231, 295, 304–320, 332–333, 412
Exemplars 50
Expectations 10
Expertise 286–289, 290
Explanation-based learning 3, 66–68, 408
Explanatory frameworks 183
Explicit memory 9, 251, 290, 291–292, 293
Eye-witness memory 269–274
Face memory 263–264
Face processing 104–105, 289–290
False belief 89, 102–104, 107, 228–231, 243–244, 245, 247, 248–249
False-font task 352
“False location” false belief task 102
False-photograph task 231
Family size 238–239
“Fast lookers” 36
Fast mapping 169–171
Feedforward inconsistency 347
Feedforward network 403
Feeling-of-knowing 301–302
Fetal activity xi
Fingerprint experts 290
Flanker task 317
fMRI xii, 104, 160–161, 217, 290, 352–355, 361
fNIRS xii, 319
Forces 208–210, 211–212
Formal-logical thought 395
Formal operational thought xviii, 374, 387–389
Foundational domains 3, 144
Fragment-completion tasks 261–263

“Fred-the-Rabbit” 198
Friends 239–242
Full object concept 3
Function, categorization 132–133
Functional magnetic resonance imaging (fMRI) xii, 104, 160–161, 217, 290, 352–355, 361
Functional near-infrared spectroscopy (fNIRS) xii, 319
Fusiform face area 104, 289–290
Fusiform gyrus 104, 289, 290, 355

Gambling 309–310
Gaze monitoring 91–92, 106–107
Generalization 109
Genes xvi, 135, 351, 399–400
“Genie” problem 325
Gesture 163–164, 411
Global to basic sequence 116–117, 118
Goal-directed actions 81–83, 85–97, 106
Goal-directed behavior 104
Goal-directed movement 129
Good information processor 296
Googing 157
Graded representations 404
Grain size 336, 337
Grammatical development 173–178, 181
Granularity problem 347
Gravity errors 214–215
Growth 133–134

Habituation paradigm 13
Habituation speed 36–37
Hand babble 158–159
Handedness xi
Hawthorne effect 344
Head turn preference procedure 156
Hebbian learning 405
Heschl’s gyrus 160, 161
Hippocampus 290–291, 402, 404–405
Holistic to analytic shift 140
“Hot” executive function 309
Human agency 47–50
Hume, D. (Humean indices) 184, 188–193
Hypotheses testing 204–206

If-then reasoning 314
If-then rules 309
Illusion of causality 43
Imagination 395, 412–413
Imitation xii, 41–42, 75, 225, 246–247, 394, see also Learning by imitation

Copyright © 2008 Psychology Press http://www.psypress.com/goswami/
Inferior frontal gyrus 161, 318, 353
Infantile amnesia 10, 255–257
Infant-directed speech (IDS) 148, 154–5
Infantile autism 10, 255–257
Infant-directed speech (IDS) 148
Inhibitory control 38, 70
Inductive reasoning xviii
Individual differences 36
Inclusion errors 204
Infant-preknowledge 405
Infant-directed speech (IDS) 148
Inhibition 135–137
Inner speech 390
Inference 275
Inside-outside distinction 130
Intelligence 35–38
Intentional action 83–85, 93–94
Intentional stance 44–45, 72, 88
Intuitions 49, 62, 75, 245–246
Interactive activation network 403
Interiorization of schemes 376, 377
Internal state terms 234
Internal state terms 234–235
Intraparietal sulcus 353
Intraparietal sulcus 353
Intraparietal cortex 292, 360–362
Intraparietal sulcus 353
Intuitive misconceptions 219
Intuitive physics 213–214
Invariance 380–384
Item analogies 322–324
"Jack-in-the-box" 189
Joint attention 75, 76, 91, 98–101, 105, 107, 224
Judgments-of-learning 299, 301
"Just like me" 80, 409
Kekule's benzene ring 321–322
Knowledge xiv, 3, 286
"Knowledge, The" 402
Labeling 165–168, 242–243
Language acquisition 147–181, 411–414
cognitive development 389–391, 398
conceptual development 125–126
connectionist models 405–406
counting 367–370
metarepresentational development 233–247, 249
mirror neurons 246–247
pretend play 222–223, 413
theory of mind 222
Language acquisition device (LAD) 51, 147
Launching events 43
Leading questions 270–272
Learning by analogy 4, 52, 64–66, 410
Learning by imitation 3, 52, 62–64, 409–410
Learning constraints x–xvi, 61, 109
Learning-to-learn 326
Left inferior frontal cortex 352
Left inferior frontal gyrus 161
Left intraparietal sulcus 353
Left lateral prefrontal cortex 319
Left lateralization 319, 351–354, 361
Left middle frontal gyrus 354
Left posterior superior temporal cortex 352, 353
Left posterior temporal cortex 352, 353
Left temporal lobe 160
Left temporoparietal region 354
Left ventral inferior frontal gyrus 353
Left ventrolateral prefrontal cortex 317–318
Lexical development 161–173, 181
Lexical stress 155–156, 160
“Like me” analogy 80, 409
Linguistic biases 125
Logic of action 375, 376
Logical search 199–202
London taxi drivers 402
"Long lookers" 36
Long-term memory 279–280
Machine learning 66, 408
Magical shrinking room 258–259
Magnet effect 151
Magnetoecephalogram (MEG) 121
Manual babbling 158–159
Mappings 143–144
Marginal babbling 157
Mark test 78
Matching-to-sample task 115–116
Maternal elaborateness 267
Mathematical development xii, 355–371
Mean length of utterance (MLU) 177
Meaning-based knowledge representations 50–51
Means–ends behavior 375
Mechanical agency 47–50
Medial prefrontal cortex 245, 247
Medial temporal lobe 290
Mediate transmission 197–199
Mediated cognition 391
Memory 4–10, 251–293, 304
Memory capacity 280
Memory span 278–279, 293
Mental representations xiii, 141, 228–233
Mental state discourse 238, 239–240, 241, 242–245
Mental states xiii, 87–97, 102
Metacognition 231, 295, 297, 304–332, 412
Metaknowing 252, 295, 297, 333
Metalinguistic awareness 337
Metamemory 295–304
Metarepresentational ability 221, 222–225, 233–247, 248, 249
Metastrategic knowing 296, 297
Microgenetic method 383
Middle frontal gyrus 353
Middle latency component 291–292
Mind blindness 89, 247
Mind-mindedness 236–238
Mirror neurons 42, 120, 245–247
Mirror self-recognition 78–79
Mismatch negativity (MMN) 159–160, 171–172
Mnemonic strategies 277, 280–281
Modality-specific knowledge 121
Modules 51, 251
Morphemes 173
Morphology 156
Mother preference 76–77
Motherese 148, 154–155
Motor analogies 377
Movement 127–129
Multivariable causal inferences 206–213
N170 104–105, 290
N400 161, 172–173
Dadrad 111, 114
Disease 384
Naive physics 3, 184, 213
Naive theories 141–143
Name learning 164–165
Natural cause 137–138
Natural kinds 111, 145
Nature versus nurture xvi–xviii
“Naughty teddy” paradigm 383
Ne component 291–292
Neo-Piagetian theories 275, 306
Neo-Vygotskians 393–395, 397–398, 413
Network architectures 403
Neural markers 160, 173, 416
Neural networks 402–403
Neuroconstructivism 399–402
Neuroimaging techniques x–xii, see also Cognitive neuroimaging
“Neuromyth” xii
Neurons xii
456  Subject index

New word invention  175–176
Nonword reading  347–348
Novel events  265–266
Novel toys  95
Novice–expert distinction  286–289, 290
Number facts  355, 361
Number sense  355, 360
Number systems  335, 355–371
Numerical relations  55–61

Object files  32
Object mechanics  51
Object memory  4–5
Object permanence  23–26, 376
Object processing  33–35
Occipital lobe  353
Oclusion relations  23–26
Oculomotor response suppression task  319
Oddity task  339, 340
Onset  337, 339–340
Onset–rime awareness  339
Operating on operations  387
Orbitofrontal cortex  309
Ordinality  363
Organizational mnemonic strategies  280, 283–285
Orthographic transparency  341–342
Overextension  168–169
“Overlapping waves” model  383–384
Over-regularization  174–175

Parental interaction style  267
Parietal cortex  292, 318, 319, 352, 353, 355, 360–362
Pedagogy  414
Peers  239–240
Perception  10–19, 41
Perceptual learning  260–261, 289–290
Perceptual magnet effect  151
Perceptual similarity  114–115, 122–125, 410
Perceptual structure  19–32, 41–52, 72–73
Perceptual to conceptual shift  140
Permission schema  330
Perseverative behaviors  70, 71, 305
Personal histories  267–269
Personification analogy  144, 322
Phoneme counting  341
Phoneme restoration  403–404
Phonemes  148–149
Phonemic awareness  340–342, 370
Phonological awareness  336–344, 370
Phonological confusability  276, 278
Phonological development  148–161, 180–181
Phonological loop  274–275, 277–280
Phonological neighbors  279
Phonological similarity effect  278
Phonological training  344–346
Phonotactic learning  153–154
Phonotactic patterns of the language  147
Phonotactic probability  153
Phonotactics  153
Physical reasoning  46
Piaget’s theory  33, 373–389
Pictorial representations  231–232
Picture-fragment completion tasks  261–262
Planning  312–315
Plausibility  217–218
Point-light displays  112, 127
Pointing  97–101, 105, 107
Posterior superior temporal sulcus  245
Posterior temporal lobe  159
Poverty of the stimulus  405
“Practice makes perfect”  289
Pragmatic reasoning schemas  329–330
Pragmatics  179–180, 181
Pre-attentive processing  352
Predictions  183
Prefrontal cortex  245, 247, 290, 317–318, 319
Premotor cortex  405
Pre-operational stage  374, 378–386
Prequantitative counting  364
Pretend play  221, 222–225, 238–245, 412–414
Primacy  6
Primary circular reactions  375
Priming  263
Principle of growth  134
Prior beliefs  204
Prior knowledge  66–67
Priority principle  184, 188, 189–190
Private speech  390
Probabilistic epigenesis  375
Problem analogies  324
Problem solving  52–61, 73
Procedural memory  9, 251
Procedural metamemory  296, 297
Processing capacity  306–307
Processing speed  38
Production deficiency  282
Projectile motion  213–214
Proportionality  387–388
Prosody  154–155
Protodeclarative pointing  97–101, 105, 107
Protoimperative pointing  97–98
Prototype formation  18
Protowards  164
Psychological reasoning  46
Psychological tools  391
Psychological utility  111
Qualitative process  xviii
Quantitative counting  364–365
Quantitative relations  55–61
Quarantining  244–245
Ratio-sensitive discrimination  356–357
Reaching  69–70
Reactive paradigm  8
Reading  120, 335, 336–355, 401
Reasoning  52–61, 73, 320–332
Recall memory  252–253
Recency  6
Reciprocal teaching  394
Recognition memory  4–5, 37–38, 251, 259–264, 292
Recurrent network  403
Redintegration  279
Regressions  375
Reinforcement cues  284–285
Relational reasoning  321–324
Relational similarity constraint  321–322
Relations  20–31
Remembering strategies  280–289
Representational capacity  42
Representational theory of mind  102
Representations, see Mental representations
Repression  255–256
Retrieval cue  284–285
Reversal learning  77
Reversibility of causal reasoning  186–187
Reversibility of thought  378
“Revolution” in social understanding  75, 85
Rhythm  156
Rico (dog)  171
Right dorsolateral prefrontal cortex  218
Right inferior frontal gyrus  318
Right inferior parietal cortex  352
Right middle temporal gyrus  353
Right parietal lobe  318
Right posterior superior temporal gyrus  353
Right superior temporal sulcus  353
Right ventrolateral prefrontal cortex  317–318
Rimes  337, 339–340
Rules of the game  396, 413

Copyright © 2008 Psychology Press http://www.psypress.com/goswami/
<table>
<thead>
<tr>
<th>Subject</th>
<th>Page(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same—different judgment task</td>
<td>339, 341</td>
</tr>
<tr>
<td>Scaffolding</td>
<td>398, 412</td>
</tr>
<tr>
<td>Scary pretence</td>
<td>244–245</td>
</tr>
<tr>
<td>Schemas</td>
<td>50, 264</td>
</tr>
<tr>
<td>Schizophrenia</td>
<td>xiv</td>
</tr>
<tr>
<td>School learning</td>
<td>392–395, 398</td>
</tr>
<tr>
<td>Scientific concepts</td>
<td>393</td>
</tr>
<tr>
<td>Scientific method</td>
<td>202</td>
</tr>
<tr>
<td>Scientific reasoning</td>
<td>202–206, 217, 410–411</td>
</tr>
<tr>
<td>Scripts</td>
<td>50, 257, 264–266</td>
</tr>
<tr>
<td>Search errors</td>
<td>69–72</td>
</tr>
<tr>
<td>Searching behavior</td>
<td>199–202, 376</td>
</tr>
<tr>
<td>Second language learning</td>
<td>405</td>
</tr>
<tr>
<td>Second-order reasoning</td>
<td>387</td>
</tr>
<tr>
<td>Secondary circular reactions</td>
<td>375</td>
</tr>
<tr>
<td>Selection task</td>
<td>328–331</td>
</tr>
<tr>
<td>Self-initiated movements</td>
<td>128–129</td>
</tr>
<tr>
<td>Self-monitoring</td>
<td>299–302, 332</td>
</tr>
<tr>
<td>Self-regulation</td>
<td>396, 397–398</td>
</tr>
<tr>
<td>Self-sustained properties</td>
<td>138</td>
</tr>
<tr>
<td>Semantic associations</td>
<td>283–285</td>
</tr>
<tr>
<td>Semantic dementia</td>
<td>367</td>
</tr>
<tr>
<td>Semantic memory</td>
<td>251, 279–280</td>
</tr>
<tr>
<td>Sensory copy system</td>
<td>247</td>
</tr>
<tr>
<td>Sensory-motor period</td>
<td>xviii, 374, 375–377</td>
</tr>
<tr>
<td>Sequential touching</td>
<td>113–115, 118–120</td>
</tr>
<tr>
<td>Seriation</td>
<td>378</td>
</tr>
<tr>
<td>Serotonin</td>
<td>399–400</td>
</tr>
<tr>
<td>Shared core properties</td>
<td>130–133</td>
</tr>
<tr>
<td>Shared function</td>
<td>132–133</td>
</tr>
<tr>
<td>Shared intentionality</td>
<td>410</td>
</tr>
<tr>
<td>Shared structure</td>
<td>132–133</td>
</tr>
<tr>
<td>“Short lookers”</td>
<td>36</td>
</tr>
<tr>
<td>Siblings</td>
<td>238–239</td>
</tr>
<tr>
<td>Sign language</td>
<td>158–159, 232</td>
</tr>
<tr>
<td>Sign systems</td>
<td>335, 391–392</td>
</tr>
<tr>
<td>Similarity</td>
<td>320–321</td>
</tr>
<tr>
<td>Similarity of cause and effect</td>
<td>192–193</td>
</tr>
<tr>
<td>Simple desire psychology</td>
<td>226–228</td>
</tr>
<tr>
<td>Simple recurrent network</td>
<td>403</td>
</tr>
<tr>
<td>Sitting</td>
<td>28</td>
</tr>
<tr>
<td>“Six-versus-a-lot” task</td>
<td>366–367</td>
</tr>
<tr>
<td>Soccer experts</td>
<td>288</td>
</tr>
<tr>
<td>Social cognition</td>
<td>80, 248</td>
</tr>
<tr>
<td>Social context</td>
<td>389</td>
</tr>
<tr>
<td>Social cues</td>
<td>153</td>
</tr>
<tr>
<td>Social interaction</td>
<td>76–77, 147, 151–153</td>
</tr>
<tr>
<td>Social mirrors</td>
<td>225</td>
</tr>
<tr>
<td>Social referencing</td>
<td>75, 76, 91, 94–97</td>
</tr>
<tr>
<td>Sociodramatic play</td>
<td>397, 413</td>
</tr>
<tr>
<td>Socioeconomic status</td>
<td>162</td>
</tr>
<tr>
<td>Source amnesia</td>
<td>303</td>
</tr>
<tr>
<td>Source monitoring</td>
<td>231, 302–304</td>
</tr>
<tr>
<td>Spatial position coding</td>
<td>23</td>
</tr>
<tr>
<td>Spatial relations</td>
<td>20–23</td>
</tr>
<tr>
<td>Speech acts</td>
<td>179</td>
</tr>
<tr>
<td>Speech rate</td>
<td>278–279</td>
</tr>
<tr>
<td>Speed of habituation</td>
<td>36–37</td>
</tr>
<tr>
<td>Speed of processing</td>
<td>38</td>
</tr>
<tr>
<td>Spontaneous concepts</td>
<td>393</td>
</tr>
<tr>
<td>Stage model</td>
<td>374</td>
</tr>
<tr>
<td>Statistical learning</td>
<td>18–19, 52, 72–73, 151, 407–409</td>
</tr>
<tr>
<td>Still face paradigm</td>
<td>91</td>
</tr>
<tr>
<td>Stress patterns</td>
<td>155–156, 160</td>
</tr>
<tr>
<td>Stroop task</td>
<td>318–319</td>
</tr>
<tr>
<td>Structural imaging</td>
<td>291</td>
</tr>
<tr>
<td>Structural similarity</td>
<td>114–115, 410</td>
</tr>
<tr>
<td>Structure, categorization</td>
<td>132–133</td>
</tr>
<tr>
<td>Subitizing</td>
<td>357</td>
</tr>
<tr>
<td>Sucking</td>
<td>375</td>
</tr>
<tr>
<td>Superior frontal sulcus</td>
<td>292</td>
</tr>
<tr>
<td>Superior temporal sulcus</td>
<td>247</td>
</tr>
<tr>
<td>Superordinate categories</td>
<td>116–118</td>
</tr>
<tr>
<td>Support relations</td>
<td>26–28</td>
</tr>
<tr>
<td>Syllabic awareness</td>
<td>338–339</td>
</tr>
<tr>
<td>Syllogistic reasoning</td>
<td>327–328, 393</td>
</tr>
<tr>
<td>Symbolic development</td>
<td>222–225</td>
</tr>
<tr>
<td>Symbolic distance effect</td>
<td>356</td>
</tr>
<tr>
<td>Symbolic play</td>
<td>396</td>
</tr>
<tr>
<td>Symbolic systems</td>
<td>257–259, 335, 371</td>
</tr>
<tr>
<td>Synaptogenesis</td>
<td>xii</td>
</tr>
<tr>
<td>Syntax</td>
<td>156</td>
</tr>
<tr>
<td>Tactile information</td>
<td>13–14</td>
</tr>
<tr>
<td>Taxi drivers</td>
<td>402</td>
</tr>
<tr>
<td>Teaching</td>
<td>143</td>
</tr>
<tr>
<td>Teaching experiments</td>
<td>67–68, 408</td>
</tr>
<tr>
<td>Teleological stance</td>
<td>87–91</td>
</tr>
<tr>
<td>Temporal contiguity principle</td>
<td>184, 189, 191–192</td>
</tr>
<tr>
<td>Temporal lobe</td>
<td>159, 160, 290, 352, 353</td>
</tr>
<tr>
<td>Temporal poles</td>
<td>245, 247</td>
</tr>
<tr>
<td>Temporally ordered events</td>
<td>252–253</td>
</tr>
<tr>
<td>Temporoparietal junction</td>
<td>245, 247</td>
</tr>
<tr>
<td>Tertiary circular reactions</td>
<td>375–376</td>
</tr>
<tr>
<td>Thematic relations</td>
<td>138–140</td>
</tr>
<tr>
<td>Theoretical learning</td>
<td>394–395</td>
</tr>
<tr>
<td>Theories</td>
<td></td>
</tr>
<tr>
<td>cognitive development</td>
<td>373–417</td>
</tr>
<tr>
<td>emergent</td>
<td>51</td>
</tr>
<tr>
<td>naïve</td>
<td>141–143</td>
</tr>
<tr>
<td>scientific reasoning</td>
<td>202–203</td>
</tr>
<tr>
<td>Theory of mind</td>
<td></td>
</tr>
<tr>
<td>causality</td>
<td>51</td>
</tr>
<tr>
<td>cognitive neuroscience</td>
<td>245–247</td>
</tr>
<tr>
<td>definition</td>
<td>221</td>
</tr>
<tr>
<td>executive function</td>
<td>315–317</td>
</tr>
<tr>
<td>friendships</td>
<td>240–241</td>
</tr>
<tr>
<td>language</td>
<td>222</td>
</tr>
<tr>
<td>metacognition</td>
<td>295</td>
</tr>
<tr>
<td>metarepresentation</td>
<td>221</td>
</tr>
<tr>
<td>pointing</td>
<td>98, 99</td>
</tr>
<tr>
<td>representational</td>
<td>102</td>
</tr>
<tr>
<td>Thought</td>
<td>376–377</td>
</tr>
<tr>
<td>Three-dimensional knowledge</td>
<td>212–213</td>
</tr>
<tr>
<td>Thumb sucking</td>
<td>375</td>
</tr>
<tr>
<td>Touch, cross-modal perception</td>
<td>13–14</td>
</tr>
<tr>
<td>Touching behavior</td>
<td>113–115, 118–120</td>
</tr>
<tr>
<td>Tower of Hanoi</td>
<td>314, 315</td>
</tr>
<tr>
<td>Transfer</td>
<td>322</td>
</tr>
<tr>
<td>Transitivity</td>
<td>378, 379–380</td>
</tr>
<tr>
<td>Triple code model</td>
<td>355</td>
</tr>
<tr>
<td>“Tubes task”</td>
<td>214–215</td>
</tr>
<tr>
<td>Tug-of-war</td>
<td>208–209</td>
</tr>
<tr>
<td>Tuition</td>
<td>143</td>
</tr>
<tr>
<td>Typicality</td>
<td>118–120</td>
</tr>
<tr>
<td>U-shaped curves</td>
<td>405</td>
</tr>
<tr>
<td>Unintentional memory</td>
<td>260</td>
</tr>
<tr>
<td>Velcro</td>
<td>322</td>
</tr>
<tr>
<td>Ventral medial prefrontal cortex</td>
<td>245</td>
</tr>
<tr>
<td>Ventral stream</td>
<td>34–35, 59–61, 120</td>
</tr>
<tr>
<td>Ventrolateral prefrontal cortex</td>
<td>317–318</td>
</tr>
<tr>
<td>Violation of expectation paradigm</td>
<td>20, 31–32</td>
</tr>
<tr>
<td>Violent pretend play</td>
<td>242</td>
</tr>
<tr>
<td>Vision, cross-modal perception</td>
<td>13–14</td>
</tr>
<tr>
<td>Visual cliff</td>
<td>95</td>
</tr>
<tr>
<td>Visual expectancies</td>
<td>10</td>
</tr>
<tr>
<td>Visual perception</td>
<td>390</td>
</tr>
<tr>
<td>Visual preference technique</td>
<td>12</td>
</tr>
<tr>
<td>Visuospatial sketchpad</td>
<td>274, 275–277</td>
</tr>
<tr>
<td>Vitalistic causality</td>
<td>142–143</td>
</tr>
<tr>
<td>Vocabulary spurt</td>
<td>163</td>
</tr>
<tr>
<td>Vocalizations</td>
<td>157, 164</td>
</tr>
<tr>
<td>Voice onset time</td>
<td>149</td>
</tr>
<tr>
<td>Vowel phonemes</td>
<td>149</td>
</tr>
<tr>
<td>Vygotsky’s theory</td>
<td>373, 389–398</td>
</tr>
<tr>
<td>Wason selection task</td>
<td>328–331</td>
</tr>
<tr>
<td>Weber’s law</td>
<td>356</td>
</tr>
<tr>
<td>Wechsler Intelligence Scale for Children</td>
<td></td>
</tr>
<tr>
<td>(WISC-R)</td>
<td>36</td>
</tr>
<tr>
<td>“What” pathway</td>
<td>34–35</td>
</tr>
<tr>
<td>“Where” pathway</td>
<td>34–35</td>
</tr>
<tr>
<td>Windows task</td>
<td>230</td>
</tr>
<tr>
<td>Wisconsin Card Sorting Test</td>
<td>305</td>
</tr>
<tr>
<td>Word combinations</td>
<td>173</td>
</tr>
<tr>
<td>Word formation</td>
<td>175–176</td>
</tr>
<tr>
<td>Word learning</td>
<td>162–163, 164–165, 181</td>
</tr>
<tr>
<td>Word length effect</td>
<td>278, 347</td>
</tr>
<tr>
<td>Word-to-world links</td>
<td>165</td>
</tr>
<tr>
<td>Working memory</td>
<td>5–6, 12, 251, 274–280, 290, 292, 293, 306–307</td>
</tr>
<tr>
<td>Zone of proximal development</td>
<td>392–395, 396–397, 398, 413</td>
</tr>
</tbody>
</table>