CHAPTER 4

Joint Attention and the Social Phenotype of Autism Spectrum Disorder: A Perspective From Developmental Psychopathology

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OVERVIEW

This chapter describes one way translational research has changed how we think about, diagnose, and treat the social impairments of autism spectrum disorder (ASD). It also relates the story of how the application of developmental science to the study of ASD has encouraged new ways of thinking about the typical development of human social-cognition. In particular, human social-cognition may be viewed as the outgrowth of a special form of human information processing that we call joint attention (Mundy & Newell, 2007). This chapter will describe how joint attention is more than a milestone in the development of social cognition in infancy. Rather, it is an executive form of information processing that contributes to social learning, stimulus encoding, and the facilitation of human social communication and connectedness across the life span. This executive joint attention function integrates information about oneself, other people, and shared attention to objects, events, or ideas. It does so through the integrated activation and functions of a distributed system of frontal and posterior cortical networks in the brain. Recognizing and understanding the parallel and distributed nature of executive joint attention functions contributes to new perspectives about the nature and development of social cognition and about the nature of the social brain in all people, including those affected by ASD (Mundy, 2003). This new framework has emerged from the

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[1]Color versions of Figures 4.3, 4.7 and 4.11 are available at http://onlinelibrary.wiley.com/book/10.1002/9781118963418

interplay between cognitive neuroscience, developmental science, and the science of autism. It integrates the idea that a "developmental analysis" (Cicchetti & Toth, 2009, p. 16), which underscores the importance of developmental timing, multiple determinants of behavior, and multiple pathways to positive or negative outcomes, is necessary to fully understand the impact of joint attention disturbance on development. As such, it provides a seminal illustration of a school of translational research that began three decades ago when a farsighted group outlined the new discipline of *developmental psychopathology* (Cicchetti, 1984; Sroufe & Rutter, 1984).

The chapter begins with a brief historical review of the conceptualization of ASD. One key message is that a lack of precise understanding of the typical developmental trajectory of social behavior impeded the accurate diagnosis of ASD until the early 1990s, which was 50 years after it was initially described by Asperger (1944) and Kanner (1943). Then we provide a review of the typical development of joint attention, the underlying neural systems supporting its development, and the utility of adopting a dynamic systems approach in understanding the neurocognitive development of joint attention. Following that review, we discuss the relation between social impairment and joint attention in ASD. This review also illustrates how social developmental research continues to be a vital source of information about the nature of ASD, and how research on ASD has led to insights about the precise nature of the typical development of joint attention in infants that have contributed to the framework for a new model of human social-cognition development. As previously noted, this chapter adopts a parallel and distributed information processing perspective on joint attention and social-cognition. An advantage of this model is that it explicitly attempts to link developmental behavioral research on social pathology to a range of recent observations, from research on neural connectivity and genetics, ocular motor control, and intervention in autism, discussed in the final section of the chapter.

A HISTORICAL PERSPECTIVE ON AUTISM SPECTRUM DISORDER

ASD is a biologically based condition that is characterized by impaired social development, impaired language, or pragmatic communication skill acquisition, and the presence of repetitive behaviors and thoughts (Asperger, 1944; Bailey, Philips, & Rutter, 1996; Dawson, Osterling, Rinaldi, Carver, & McPartland, 2001; Kanner, 1943). The symptoms of ASD in many affected children are observable by 24 months of age or earlier (Stone, Coonrod, & Ousley, 1997; Zwaigenbaum et al., 2005), with children expressing different courses of symptom onset. Some children may display clear symptoms by the end of the first year or early part of the second year of life. Other children may display more typical development through the first year but then not display the typical rate of advances in social communication behaviors in the second year, while others may display a second year course more indicative of the interruption or loss of elements of social communication development (Ozonoff, Heung, Byrd, Hansen, & Hertz-Picciotto, 2008).

Leo Kanner (1943) displayed impressive clinical acumen when he was able to discern three common characteristics that distinguished children with ASD from those in a larger clinical sample of children with varied exceptionalities. He noted that children with ASD appeared to have (1) a common impairment of affective relatedness to others, which (2) resulted in a disorder that primarily involved impairments of the capacity for typical social interactions and (3) was most likely caused by biologically based processes. The recognition of the biological, affective, and social-behavioral syndrome triumvirate of autism was a remarkable achievement and is as valid today as it was in 1944. Unfortunately, Kanner's initial perspective did not fit well with the psychodynamic zeitgeist of the time. The psychodynamic perspective of the time emphasized the primacy of environmental over biological factors in the etiology of all psychopathology. Sufficient challenges were brought to bear in this regard that Kanner (1949) recanted in his initial biological view of ASD.

In the ensuing thirty years, the science of autism drifted from one perspective to another. ASD was described as a disorder caused by an aloof parenting style that caused children to grow up to be severely emotional disengaged from all people (Bettleheim, 1959). By the early 1960s, compelling indirect evidence for the biological nature of ASD had been presented to counter this parenting style hypothesis (e.g., Rimland, 1964). However, the singular prototype of people with ASD as emotionless and aloof remained for a long time. Few data were available to critically appraise prototype because the social and emotional development of children with ASD was rarely a focus of empirical inquiry through the 1970s. For example, Pat Howlin (1978) required only seven pages and 39 citations to review the literature on the social behavior of children affected by ASD at the time. Moreover, only a handful of the citations referred to peer-reviewed empirical research publications on the social behavior of ASD. Alternatively, research and theory at that time was taken with the notion that sensory, perceptual, or language impairments must be primary to the phenotype and etiology of ASD (Mundy & Sigman, 1989a). Although this was a scientifically valid assumption given the dearth of any appreciable empirical research on autism, it had the untoward consequence of relegating social-emotional impairments to the status of epiphenomenon in models of ASD. The secondary status of social-emotional symptoms constrained the theory and methods used to establish the initial diagnostic criteria for ASD.

DIAGNOSTIC DESCRIPTION OF ASD

The first attempts in the USA to establish a systematic diagnostic definition of ASD were in the third edition of the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM-III;* American Psychiatric Association, 1980). *DSM-III* described only six symptom criteria for the diagnosis of autism: (1) onset before 30 months of age; (2) a pervasive lack of responsiveness to other people; (3) gross deficits in language development; (4) if speech is present, peculiar speech patterns such as immediate and delayed echolalia, metaphorical language, pronominal reversal; (5) bizarre responses to various aspects of the environment, (e.g., resistance to change, peculiar interest in or attachments to animate or inanimate objects); and (6) absence of delusions, hallucinations, loosening of associations, and incoherence as in schizophrenia.

The item in this initial set of symptoms that was specific to the social deficits of autism was the rather broad and vague descriptor of a pervasive lack of responsiveness to other people. There had been so little research on defining the nature of the social deficits of autism through 1980 that we simply had no idea how to precisely describe this symptom domain of ASD, even though Kanner had argued that it was the central symptom domain of the syndrome. Fortunately, in the subsequent decade there was a virtual explosion of research on the social-deficits of ASD. Indeed, when Pat Howlin published a second review of research on the social development of ASD, eight years after her first effort in 1978, she required 24 pages and 116 citations to adequately cover the field (Howlin, 1986).

This welcome increase in information on the social nature of ASD occurred because of translational research. Several groups in the United States, the United Kingdom, and throughout the world began to recognize that theory and methods used in the study of human infancy and primate social development could be used as powerful tools to examine and define the social deficits of ASD (e.g., Baron-Cohen, Leslie, & Frith, 1986; Cicchetti, 1984; Dawson & McKissick, 1984; Rogers & Pennington, 1990; Sigman & Ungerer, 1984; Wimmer & Perner, 1983); more recently, there has been acknowledgement that the social deficits of ASD may provide important insights on typical development, as well (Cicchetti & Toth, 2009). This new wave involved the translation of the basic developmental science studies of infant imitation, social learning, social cognition, preverbal communication, and attachment, as well as social cognitive development in young children. One fairly immediate and vital impact of this surge of translational research was the dawning awareness that the description of the social impairments of ASD singularly as a *pervasive lack of responsiveness to others* was at best limited and, at worst, misguided. That description established an ASD prototype of a completely socially unresponsive child, but empirical research indicated that this prototype did not effectively characterize the spectrum of children that were affected by the syndrome (Mundy & Sigman, 1989; Wing & Gould, 1979).

One of the most fundamental observations in the science of autism is that the expression of the social phenotype of ASD varies across children (Wing & Gould, 1979). Wing and Gould (1979) found that some children with ASD appeared to be socially aloof, much as the description of "a pervasive lack of responsiveness" suggests. These aloof children often performed in the severe or moderate range of intellectual disabilities on measures of IQ or developmental status. However, many other children with mild intellectual disabilities, or IQs in the typical range were not pervasively underresponsive. Instead, some were passive but socially responsive in structured situations. Other children were even proactive in initiating interactions. However, while socially more active, these children displayed social behavior that was odd, atypical, and frequently maladaptive in engaging or maintaining interactions with other people (Fein et al., 1999; Volkmar, Cohen, Bregman, Hooks, & Stevenson, 1989; Wing & Gould, 1979).

In addition to the recognition of the Wing and Gould tripartite social typology of ASD, by the end of the 1980's, studies had reported the observation that many children with ASD displayed patterns of social strengths, as well as weaknesses, rather than only a pattern of a *pervasive lack of responsiveness to other*s. For example, children with ASD responded when others imitated them, and some children appeared to learn from observing social modeling. Many children reportedly increased their social behaviors in structured situations, and children with ASD varied greatly in their use of gestures and eye contact to communicate (Curcio, 1978; Lewy & Dawson, 1992; Mundy & Sigman, 1989). Perhaps most remarkably, children with ASD often displayed levels of attachment behaviors that were commensurate with their mental development and *not atypical* relative to other groups of children with comparable developmental delays (Mundy & Sigman, 1989; Shapiro, Sherman, Calamari, & Koch, 1987; Sigman & Ungerer, 1984). In these studies, measures of attachment were used that assessed children's responses to separations, and, especially, reunions with their caregivers. Many children with ASD displayed behaviors that suggested they had developed emotional bonds that were specific to their caregivers and that supported the children's self-regulation in a strange laboratory environment. Such displays of social bonding to caregivers were wholly inconsistent with many of the then current models of ASD, including the notion that all affected children displayed a universal lack of responsiveness to others.

Consequently, by the early 1990s translational developmental research indicated that key elements of the nosology of ASD were incorrect. Children with ASD, as a group, did not display a *pervasive* lack of responsiveness to others. Not only was this inaccurate, it promoted a constricted view of ASD that excluded many children with the syndrome who frequently made eye contact, or displayed caregiver attachment, or any of a number of other social abilities. The persistence of this inaccurate taxonomic prototype likely contributed to a historic underestimation of the prevalence of ASD (Wing & Potter, 2002). Indeed, only with the publication of the fourth edition of the *DSM*, in 1994, did we begin to have sufficiently well-defined guidelines that both accurately captured something of the essence of the core social impairments of ASD, and acknowledged the range of phenotypic variability expressed across individuals with this syndrome. Prior to this, in the 1970s, 1980s, and early 1990s, we simply could not identify all the children with ASD in the population because we limited ourselves to those that just met a very limited and restrictive social criterion.

Research-based revisions of social diagnostic criteria of ASD by both the American Psychiatric Association (APA, 1994, 2000, 2013) and the International Classification of Disease (ICD), established by the World Health Organization (1991), have led to more effective and informed ASD identification and diagnosis. In the most recent revision (*DSM-5*; APA, 2013), the persistent impairment in social communication and interaction in ASD became defined in terms of the expression of the following symptoms: (1) deficits in social-emotional reciprocity, ranging from abnormal social approach and failure of normal back-and-forth conversation to reduced sharing of interests, emotions, or affect, to failure to initiate or respond to social interactions; (2) deficits in nonverbal communicative behaviors used for social interaction, ranging from poorly integrated verbal and nonverbal communication to abnormalities in eye contact and body language or deficits in understanding and use of gestures, to a total lack of facial expressions and nonverbal communication; (3) deficits in developing, maintaining, and understanding relationships, ranging from difficulties adjusting behavior to suit various social contexts to difficulties in sharing imaginative play or in making friends to absence of interest in peers.

"Deficits in relationships, or lack of sharing imaginative play or in making friends" as a symptom item is extremely useful, but not until children reach 3 or 4 years of age. As a result, the early identification and diagnosis of the social deficits of ASD relies on observation of the other social symptoms, which heavily draw from the concept of joint attention. Thus, this chapter attempts to provide a detailed consideration of why joint attention, operationalized as sharing interests, emotion, or affect, or initiating or responding to other people, via eye contact and nonverbal communication, is central to the description of the social pathology of ASD, and the very nature of this syndrome.

JOINT ATTENTION IN TYPICAL DEVELOPMENT

Well before infants learn to use symbols and language, they begin to spontaneously share information with other people. They do so by coordinating their attention with another person and by using eye contact and gestures to show objects to others, as well as to request objects or events (Bates, Benigni, Bretherton, Camaioni, & Volterrra, 1979). In a seminal paper in *Nature,* in 1975, Scaife and Bruner reported that between 6 to 18 months of age infants increasingly displayed the ability to follow the direction of gaze of a social partner. When a tester turned her head to the left or right many infants tracked and followed the visual attention of the tester with their own line of regard. This observation was groundbreaking. It was inconsistent with the prevailing notion of egocentrism or the idea that infants could not adopt dual perspectives, such as the perspective of self and another person, until late in the second year (Piaget, 1952). Scaife & Bruner's (1975) observations suggested that infants begin to differentiate information about their own visual perspective and that of another person, and then align their perspective with another person's much earlier in life than that.

Bruner (1975) adopted the general term *joint attention* for this domain of infant development. He recognized that this ability allowed infants and caregivers to adopt co-reference to the same object or event, and that this ability was a milestone in human social learning. One of Bruner's goals was to understand how young children learn, in order to improve early educational curriculums. Instead of studying only how knowledge was acquired (learning), he studied how the ability to share knowledge in social learning develops because this is essential to all forms of pedagogy. His work suggested that the development of the ability to participate in joint attention marked a critical turning point in some unknown set of early cognitive processes that enabled young children to more effectively benefit from caregiver scaffolding. Indeed, the emergence of joint attention ability in infants may even elicit or promote scaffolding in caregivers, suggesting that a multiple-level, bidirectional analysis of joint attention behavior in dyads would be necessary to fully understand the process (Cicchetti & Toth, 2009). Bruner, along with others before him (e.g., Werner & Kaplan, 1963), understood that the development of the capacity to adopt a common point of view (shared reference) was elementary to our human ability to perceive shared meanings and necessary for the development of symbolic thinking and language development.

Measurement of Subtypes of Joint Attention

In the early days of research, it became apparent that infants did not just develop one type of joint attention behavior. Rather, the development of joint attention was expressed in different functional forms in infancy (Bates et al., 1979). Infants may *respond* to others' joint attention bids or *initiate* joint attention bids (Seibert, Hogan, & Mundy, 1982). They do so to share declarative or imperative information about an object or event (Bates et al., 1979). In the declarative function, infants use their line of regard and gestures to share their experience of an object or event (e.g., interest) with another person, or they respond to others' attempts to indicate their experience of an object or event. These two types of behaviors came to be known as initiating joint attention (IJA) and responding to joint attention (RJA), respectively (Seibert et al., 1982). Current data supports the observations of Scaife and Bruner (1975) and indicates that infants begin to reliably turn their head or eyes to follow the visual line of regard of another person by 6 months of age (Gredebäck et al., 2010; Figure 4.1a). Less is known about the development of IJA, but data suggest that the ability to alternate eye contact between an object or event and another person, to spontaneously share interest or experience with a social partner, is well developed in many 8–9-month-olds (Bates et al., 1979; Mundy et al., 2007; Figure 4.1b, Figure 4.1c).

The declarative, social sharing functions of IJA and RJA can be juxtaposed with other behavior that involve establishing a common point of reference with other people for instrumental and imperative purposes (Bates et al., 1979). By 9 months of age, infants direct the attention of other people to express their desires (e.g. request) for an object or event using initiating behavioral requests (IBR; Figure 4.1d). In addition, they learn to respond to the attention directing bids that adults use to request objects or actions from infants. This is referred to as responding to behavioral requests (RBR; Figure 4.1e).

The theory and measurement concerning infant joint attention in the 1970s and 1980s interacted with the contemporary concern with identifying valid infant markers of individual differences in cognitive development. The types of sensory motor measures then used to assess infant intelligence and cognitive risk at the time were not sufficiently reliable or valid (Lewis & McGurk, 1972). Without valid measures, it was challenging to identify many infants who were at risk for developmental disorders. It was also difficult to know what constituted valid targets for early cognitive intervention. This impasse began to clear as applications of basic research indicated that measures of infant visual attention could be used as valid indicators of current and future cognitive development in infancy (Bornstein & Sigman, 1986). Although not fully appreciated at the time, this assertion could be expanded to include measures of infant *joint attention* development (Sigman & Mundy, 1993).

One laboratory for research on infant attention was created by Jeff Seibert and Anne Hogan at the Debbie School of the University of Miami. The Debbie School served preschoolers who had moderate to severe motor and developmental impairments. Their motor impairments made the use of sensorimotor cognitive assessments and interventions extremely impractical. So Seibert, Hogan, and their graduate student began to develop an early assessment and intervention curriculum that focused on joint attention and preverbal communication skill development. This resulted in the Early Social Communication Scales (ESCS), which organized precise observations of joint attention and social attention coordination into a measurement instrument that could also be used to guide early intervention (Seibert, Hogan, & Mundy, 1982). A lasting contribution of the ESCS, along with related measures (Stone, Coonrod, & Ousley, 1997; Wetherby, Allen,

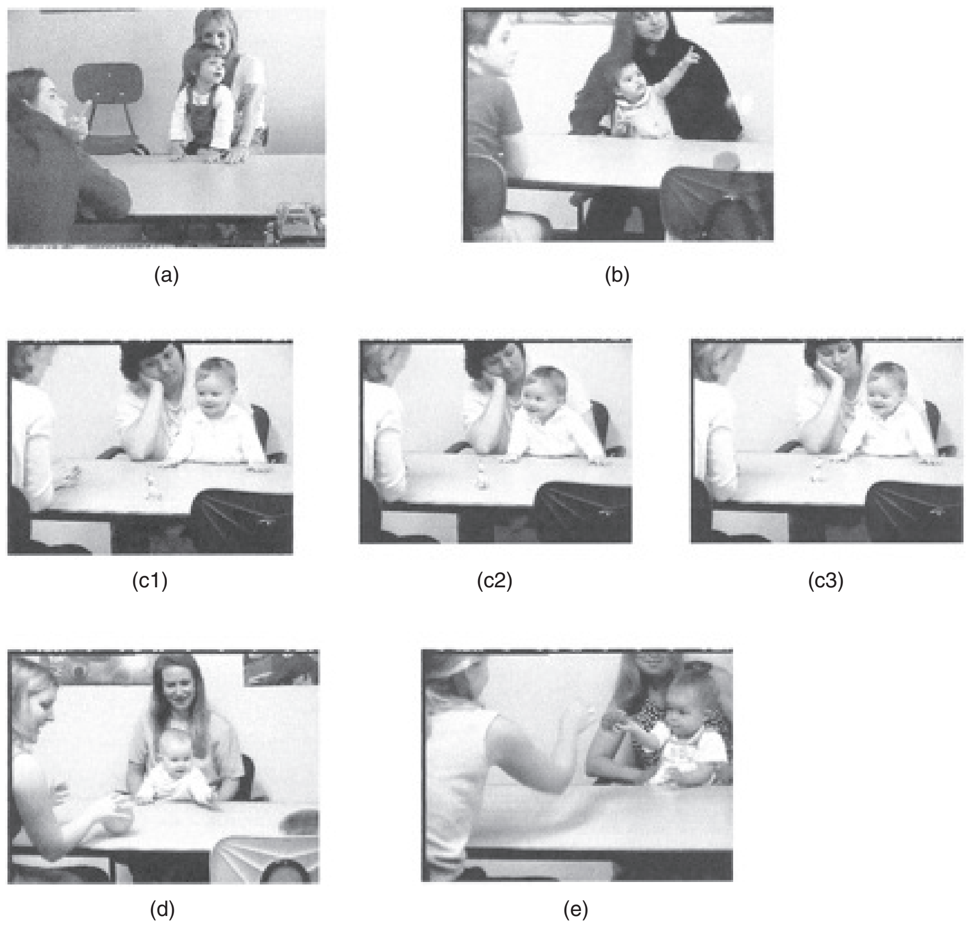

Figure 4.1 Illustrations of different types of infant social attention coordination behaviors: (a) responding to joint attention (RJA): following another person's gaze and pointing gesture; (b) initiating joint attention (IJA): using a conventional gesture (such as pointing) to share attention regarding a room poster; (c1,2,3) IJA: using an alternation of eye contact to share attention with respect to a toy; (d) initiating behavior requests: pointing to elicit aid in obtaining an out of reach object; (e) responding to behavior requests: following an adult's open-palm give-it-to-me gesture.

Cleary, Kublin, & Goldstein, 2002) was that joint attention assessment turned out to be a powerful instrument for the study of ASD and individual differences in social learning capabilities.

Learning and the Importance of Joint Attention

Early language learning often takes place in unstructured, incidental situations where parents spontaneously refer to a new object (Figure 4.2). How do infants know how to map their parents' vocal labels to the correct parts of the environment amid myriad potential referents? Baldwin (1995) suggested that they use RJA and use the direction of their parent's gaze to guide them to the correct area of the environment, thereby reducing referential mapping errors. Infants' use of IJA also reduces the chance of referential mapping errors. IJA serves to denote something of immediate interest to the child. This allows parents to follow their child's attention to provide new information in a context when the child's interest and attention is optimal for learning (Tomasello & Farrar, 1986). Hence, joint attention may be conceived of as a self-organizing system that facilitates information processing in support of social learning (Mundy, 2003). This learning function is fundamental to the nature of joint attention as a milestone of early development (Bruner, 1975). Moreover, joint attention continues to operate throughout our lives in many ways, such as affecting our emotional responses to stimuli (Bayliss et al., 2006), facilitating math learning (Nathan, Eilam, & Kim, 2007), improving mental spatial rotation in adults (Böckler, Knoblich, & Sebanz, 2011), affecting recognition memory in adults (Kim & Mundy, 2012), and facilitating or changing stimulus processing (Frischen et al., 2007). Indeed, it is safe to say that without the

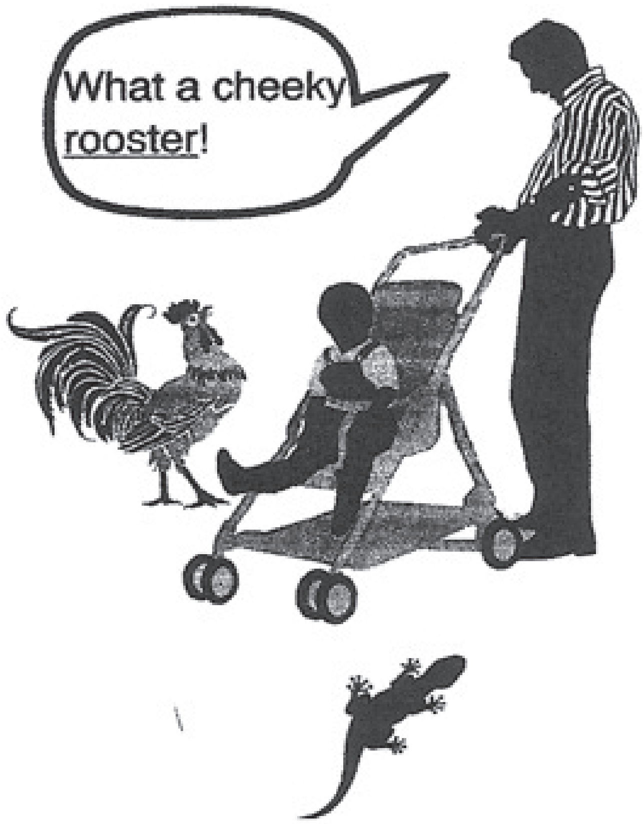

Figure 4.2 Illustration depicting the referential mapping problem encountered by infants in incidental social word learning situations. *Source:* D. Baldwin, Understanding the link between joint attention and language, in C. Moore & P. Dunham (Eds.), *Joint attention: Its origins and role in development* (pp. 131–158), Hillsdale, NJ: Erlbaum, 1995.

capacity for joint attention, success in many pedagogical contexts would be difficult. Imagine the school readiness problems of a 5-year-old who enters kindergarten, but is not facile with coordinating attention with the teacher. Similarly, children, adolescents and adults who cannot follow, initiate, or join with the rapid-fire exchanges of shared attention in social interactions may be impaired in any social-learning context, as well as in their very capacity for relatedness and relationships (Mundy & Sigman, 2006).

To the degree that joint attention helps self-organize social learning in infancy, the more that children engage in joint attention, the more optimal social-learning opportunities they will help create for themselves. This may help to explain why the frequency with which infants engage in joint attention is positively related to their language acquisition and childhood IQ status (e.g., Mundy et al., 2007; Smith & Ulvund, 2003). More direct evidence of the links between joint attention and early learning is provided by the observation that coordinated social attention to pictures elicits electrophysiological evidence of enhanced neural activity and recognition memory associated with greater depth of processing in 9-month-olds (Kopp & Lindenberger, 2011; Striano, Chen, Cleveland, & Bradshaw, 2006; Striano, Reid, & Hoel, 2006).

Joint Attention and the Social-Cognitive Hypothesis

During the time that joint attention was first being conceptualized, another relevant kind of translational cognitive research was beginning to emerge. Premack and Woodruff (1978) described observational methods that enabled them to evaluate whether primates were aware of the thoughts or intention of conspecifics. That is, they began to study if apes had a theory of mind (ToM). Wimmer and Perner (1983), in the United Kingdom, further operationalized the construct of theory of mind with the development of the false belief task. With this paradigm they began to study the course of development of ToM and social cognition in preschool- and elementary school–age children.

Theory had previously linked the development of joint attention to the emergence of social cognition (Bretherton, 1991). This was further extended to its logical conclusion; namely, that young children would only consistently respond to or initiate joint attention bids if they understood that other people exerted intentional (goal-directed) control over their attention (Tomasello & Call, 1997). There was a cardinal problem with this model. Specifically, developmental studies indicated that infants displayed a wide range of individual differences in the frequency of their joint attention bids. For example, a large sample study indicated that 9-month-old infants displayed between four and forty IJA bids in a 20-minute interaction with an unfamiliar tester (Mundy et al., 2007). This variance was meaningful, in that the individual differences in IJA were reliable from 9 to 18 months of age (Figure 4.3). The social cognitive model was not developed to account for individual differences. Rather, it was an attempt to explain an all or none phenomenon, such as why older but not younger children display joint attention, or why typical children but not children with developmental disabilities display joint attention. However, joint attention does not simply develop in an all or none fashion. Some infants and children, with and without ASD, engage in more joint attention than others (e.g., Mundy, Sigman, & Kasari, 1990). It is very difficult to explain individual differences in joint attention on the order of those displayed in Figure 4.3 in terms of some scheme of incremental differences in understanding intentionality in others, at least as far as the social cognitive model has been articulated to date.

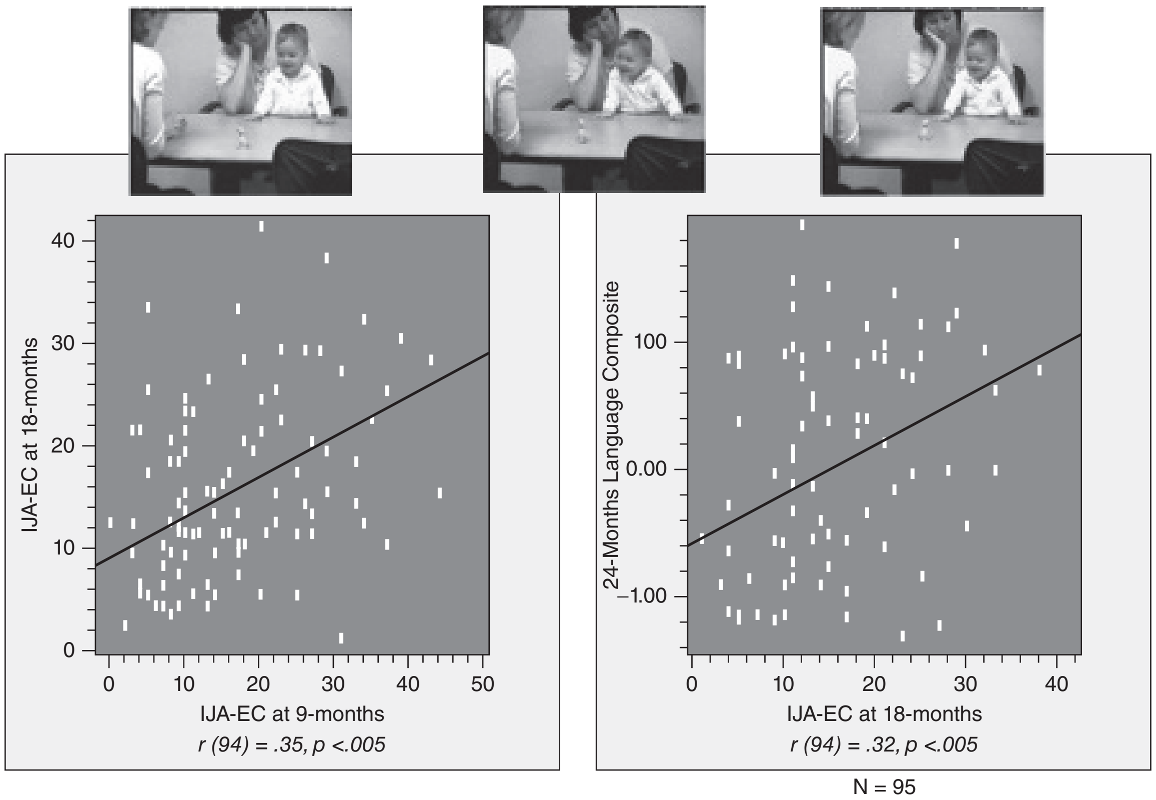

Figure 4.3 Illustration of the range and stability of individual differences in IJA alternating eye contact in 95 infants between 9 and 18 months of age (left panel), and the meaningful nature of individual differences in IJA alternating eye contact for a combined measure of receptive and expressive vocabulary development at 24 months. See footnote 1. *Source:* Data illustrations from P. Mundy, J. Block, A. Vaughan Van Hecke, C. Delgado, M. Venezia Parlade, & Y. Pomares, Individual differences and the development of infant joint attention, *Child Development, 78,* 938–954, 2007.

In summary, infant translational research provided a foundation for understanding the importance of joint attention for human development. Joint attention, by reflecting the capacity to share experiences and connect with others, likely provides a foundation for relational experiences with other people across the lifespan. Joint attention also provides a foundation for co-occurring and subsequent developments in language, thinking about others' minds, social learning, and social-emotional competence. It is not surprising, then, that the next major area of inquiry to develop would address better understanding the *neural foundations* of joint attention and its associated social-emotional outcomes.

THE NEURAL SYSTEMS OF JOINT ATTENTION

The neural systems associated with IJA and RJA development may be best understood within the context provided by two primary hypotheses within the contemporary research on functional brain architecture. The first hypothesis is that human cognition is best characterized as an emergent property of interactions among distributed, functionally specialized brain networks (McIntosh, 2000; Ramnani, Behrens, Penny, & Matthews, 2004). The second hypothesis is that there are at least *three superordinate brain networks* that interact in the development of cognition. These include the default network, which supports internal or self-referenced cognition, the dorsal attention system that serves external and other-referenced cognition, and the frontoparietal control or executive network, which regulates the expression or integration of the default and dorsal attention networks in cognition (Spreng, Sepulcre, Turner, Stevens, & Schacter, 2013; Figure 4.4). The default and dorsal attention systems show little evidence of positive (interactive) connectivity and may conflict or inhibit functions of the opposing network. Alternatively, the frontoparietal network has positive connectivity with both the default and dorsal attention networks. Moreover, Spreng et al. (2013) identified three different types of

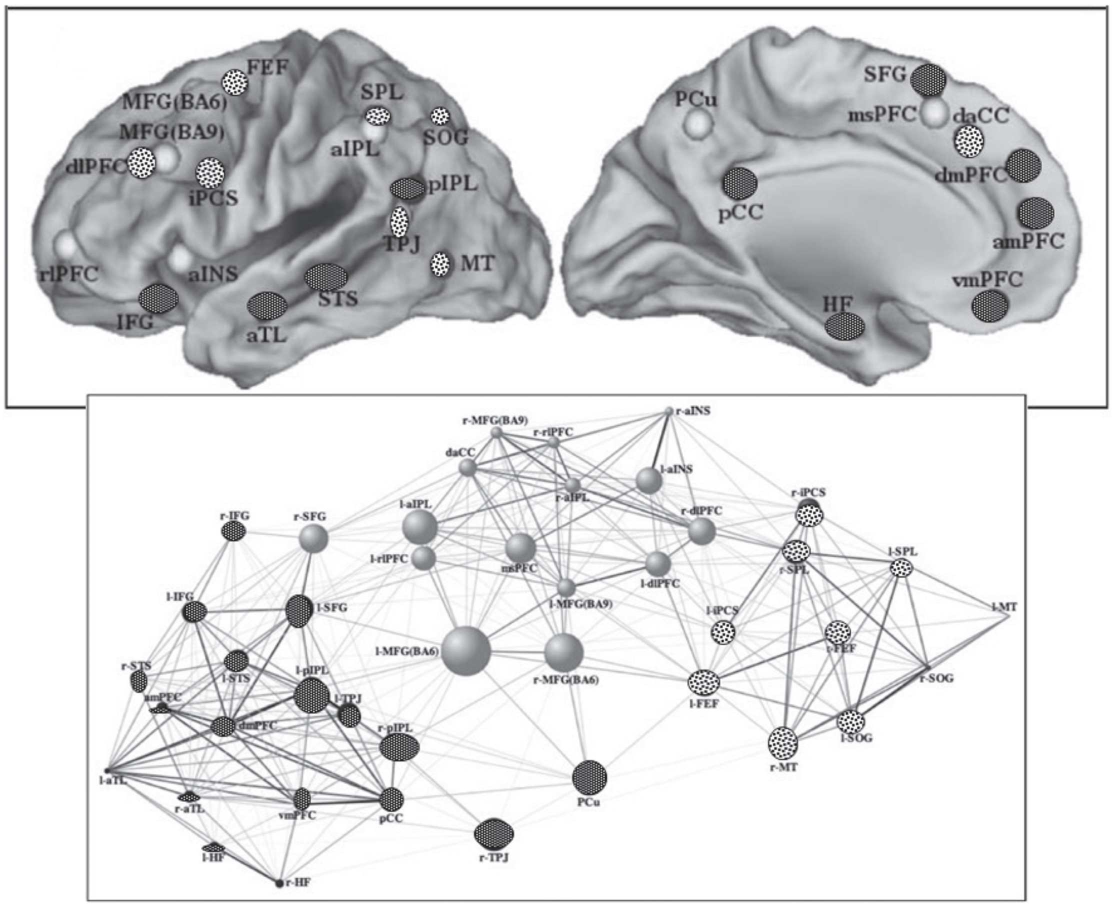

Figure 4.4 Illustration of the default network (circles with black background and white dots), frontoparietal network (circles in grayscale), and the dorsal attention network (circles with white background and black dots) in the top panel, and connectivity within and across networks in the bottom panel. *Source:* From R. N. Spreng, J. Sepulcre, G. R. Turner, W. D. Stevens, & D. L. Schacter, Intrinsic architecture underlying the relations among the default, dorsal attention, and frontoparietal control networks of the human brain, *Journal of Cognitive Neuroscience, 25*(1), 77, 80, 2013.

nodes within the frontoparietal network: default network aligned nodes, dorsal network aligned nodes, and dual aligned nodes. These nodes are thought to play a dynamic gatekeeping role in goal-directed cognition, mediating the adaptive balance between internal and external cognition, from moment to moment, across tasks and contexts. Regarding the development of these networks, Spreng et al. (2013, p. 82) noted, "Evidence suggests that patterns of intrinsic connectivity are sculpted by a history of repeated task-driven co-activation of brain regions, which in turn facilitates efficient coupling within task-relevant networks during future task performance." In other words, experience-based co-activity sculpts connectivity over time, which in turn affects later capacities (Cicchetti & Toth, 2009; Greenough, Black, & Wallace, 1987).

Early research on the similar and different processes that contribute to IJA and RJA emphasized the role of the dorsal attention network (Mundy, 2003). The dorsal attention network involves an anterior (frontal) and a posterior (temporal/parietal) component (Posner & Rothbart, 2007). Early studies suggested that IJA was more associated with the anterior attention network (Caplan et al., 1993; Henderson, Yoder, Yale, & McDuffie, 2002; Mundy et al., 2000; Torkildsen, Thormodsen, Syvensen, Smith, & Lingren, 2008), while RJA and related gaze-following behaviors were more closely associated with the posterior attention network (e.g., Emery, 2000; Frischen, Bayliss, & Tipper, 2007; Materna, Dicke, & Thern, 2008; Mundy et al., 2000). Interestingly, this observation provided one explanation of why higher primates (apes) were capable of RJA but not IJA (Tomasello, 2008). Several research groups have reported observations that suggest that the functions of the posterior network that support RJA are common to many primates, but the anterior network that supports IJA is not well represented in primates other than humans (Astafiev, Shulman, Stanley, Snyder, Essen, & Corbetta, 2003; Emery, 2000; Gilbert & Burgess, 2008; Jellema, Baker, Wicker, & Perrett, 2000).

The posterior dorsal attention network regulates relatively involuntary attention, begins to develop in the first 3 months of life, and prioritizes orienting to biologically meaningful stimuli. It is supported by neural networks of the parietal/precuneous and superior temporal cortices (Figure 4.5). These neural networks are active in the perception of the eye and head orientations of others, as well as the perception of spatial relations between self, other, and the environment. The posterior system is especially involved in control of orienting on a trial-by-trial basis and the development of cognitive representations about the world built from information acquired through external senses (Cavanna & Trimble, 2006; Dosenbach et al., 2007; Fuster, 2006). This characterization of the posterior attention system comports with the notion that RJA is a relatively involuntary or reflexive response to human gaze shifts (Frischen et al., 2007).

In contrast, initiating joint attention was thought to be supported by later developments of the anterior dorsal attention network which were involved in cognitive processing addressing volitional, self-initiated, goal-directed action (Mundy, 2003). This network includes the anterior cingulate, rostral medial superior frontal cortex (including the frontal eye fields), anterior prefrontal cortex, and orbital frontal cortex (e.g., Dosenbach et al., 2007; Fuster, 2006). The development of the intentional control of visual attention is thought to begin at about 3 to 4 months of age. At that time, a pathway from the frontal eye fields (BA 8/9) begins to release the superior colliculus from inhibition, which enables the development of active prospective control of saccades and visual attention (Canfield & Kirkham, 2001; Johnson, 1990). The function of this pathway may underlie 4-month-old infants' ability to suppress automatic visual saccades to respond to a second, more attractive stimulus (Johnson, 1995), and 6-month-olds' ability to respond to a peripheral target when central, competing stimuli are present (Atkinson, Hood, Wattam-Bell, & Braddick, 1992). Hypothetically, the functions of this pathway also enable intentional gaze alternation between interesting events and social partners (Mundy, 2003).

More recent research suggests that it may not be accurate to allocate IJA exclusively to anterior systems functions, and RJA to posterior system functions. Indeed, reliance only on the dorsal attention network is likely insufficient to characterize the complete system of neural networks that are involved in the maturation of human joint attention. For example, Schilbach et al. (2010) used imaging (fMRI) to examine whether the cortical correlates of RJA and IJA were common or distinct in adults. This research group reported that joint attention elicited activation in a specific frontal-temporal-parietal distributed network, that likely contains elements of the default and

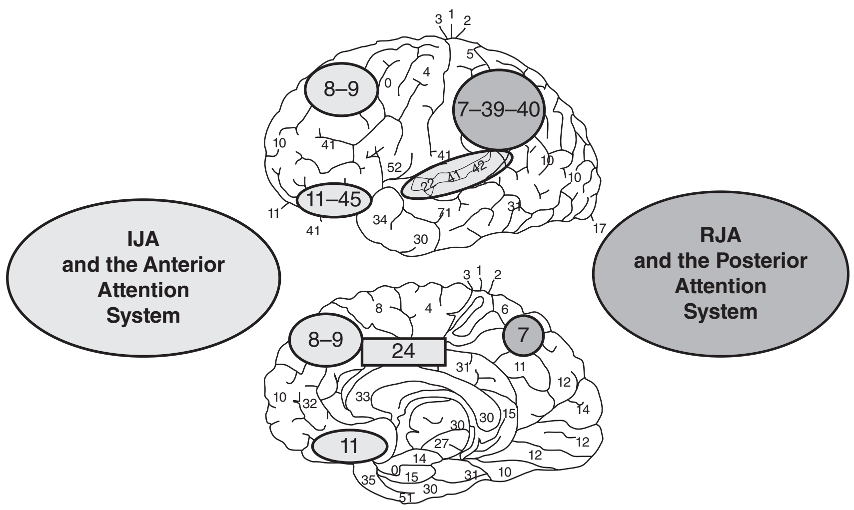

Figure 4.5 Illustration depicting the lateral (top) and medial (bottom) illustrations of Brodmann's cytoarchitectonic areas of the cerebral cortex associated with initiating joint attention and the anterior attention system, as well as RJA and the posterior attention systems. The former include areas 8 (frontal eye fields), 9 (prefrontal association cortex), 24 (anterior cingulate), 11, and 47 (orbital prefrontal association cortex). The latter include areas 7 (precuneous, posterior parietal association area), 22, 41, and 42 (superior temporal cortex), and 39 and 40 (parietal, temporal, occipital association cortex). *Source:* Illustration from P. Mundy & L. Newell, Attention, joint attention and social cognition, *Current Directions in Psychological Science*, *16*, p. 271, 2007.

frontoparietal network, as well as the dorsal attention network. Moreover, Schilbach et al. (2010) observed that RJA, but not IJA, was uniquely associated with medial frontal gyrus activation, a region that is part of the frontoparietal control network in the Spreng et al. (2013) model. Consistent with this observation, recent behavioral development studies also suggest that executive cognitive control functions are associated with RJA in infancy (Vaughan Van Hecke et al., 2012). In contrast, Schilbach et al. (2010) observed that IJA was more exclusively associated with striatal cortex activation than was RJA. Striatal cortex is associated with reward processing that is instrumental to motivating self-initiated goal directed behavior. This observation is consistent with the notion that prosocial motivation likely plays a role in IJA development (Vaughan Van Hecke et al., 2007). The ventral striatum is not represented in the Spreng et al. (2013) model, however; it is part of a reward-processing network that involves elements of the Default Network described by Spreng and colleagues, such as the dorsal medial prefrontal cortex (mPFC) (Carlson, Foti, Mujica-Parodi, Harmon-Jones, & Hajcak, 2011).

Subsequently, Redcay et al. (2012) reported a seminal sequence of fMRI observations on joint attention with adults. In this study, both IJA and RJA were associated with the activation of the posterior superior temporal sulcus and the mPFC, which are components of the default network (Spreng et al., 2013) often associated with social cognition. IJA displayed relatively stronger association with activation in the middle frontal gyrus and parietal cortex, areas associated with the dorsal attention and frontoparietal control networks described by Spreng et al. (2013). Alternatively, RJA was uniquely associated with ventral medial frontal and occipital cortical activation in this study. Only the former is included in the Spreng model and is aligned with the default network. Perhaps most interesting of all, Redcay et al. (2012) provided the only connectivity analysis to date and found evidence that joint attention is associated with functional connectivity among nodes that are part of all three networks described by Spreng et al. (2013).

Of course, the neurofunctional organization observed in adults may not necessarily inform our understanding of the developmental systems that give rise to the early development of joint attention. However, studies indicate that many elements of a distributed joint attention network, that are evident in research with adults, are also evident in early developmental research with infants. Grossman and Johnson (2009) reported that a pattern of anterior (medial frontal, left ventral frontal) and posterior (right temporal/parietal) cortical activation is associated with response to joint attention in 5-month-olds. Elison et al. (2013) also reported that the relative functioning of anterior frontal white matter fiber tracts (uncinate fasciculi) and posterior temporal white matter fiber tracts (inferior longitudinal fasciculi) at 6 months of age predicts RJA development at 9 months of age. It is also the case that a pattern of EEG activation across a distributed anterior and posterior cortical system predicts IJA development in infants from 14 to 16 months of age (Henderson et al., 2002).

Thus, the current research literature has given rise to the parallel and distributed processing model (PDPM) of joint attention development and its impairment in ASD (Mundy et al., 2009). According to this model, initial executive and behavioral motivation biases promote the tendency of infants to engage in the practice of processing of internal information about the direction and focus of their own visual attention, while also processing external information about the visual attention of other people. This dynamic system of early self-other information processing about attention leads to the concretization of connections between an anterior and posterior neurocognitive network that supports fast and efficient human joint attention (Figure 4.6; Mundy & Newell, 2007). This model incorporates the notion that patterns of what may appear to be intrinsic connectivity in adults have been sculpted by a history of repeated (practiced) task-driven co-activation of brain regions during development (Cicchetti & Toth, 2009; Spreng et al., 2013). The model is also consistent with neurocognitive theory that claims that an emergent function of the human rostral-medial frontal cortex is the capacity to switch attention between self-generated information and perceptual (external) information in support of social cognition (Gilbert & Burgess, 2008). The PDPM suggests that this function is allocated to the rostral medial frontal cortex, in large part, as a function of the adequate bio-behavioral exercise of joint attention behaviors early in development. Moreover, if behavioral practice does not facilitate efficient couplings within task-relevant networks, then the joint attention system may display quantitative reductions in its rapid and efficient execution. This, in turn results in increased cognitive load associated with joint attention engagement and consequent reduced effectiveness of cognitive processing within social interactions, such as social learning situation or social conversational discourse (Mundy & Jarrold, 2010; Mundy et al., 2009, 2010).

Recently, two studies have provided evidence that part of the development of joint attention early in life may be characterized by an increase in the speed or efficiency with

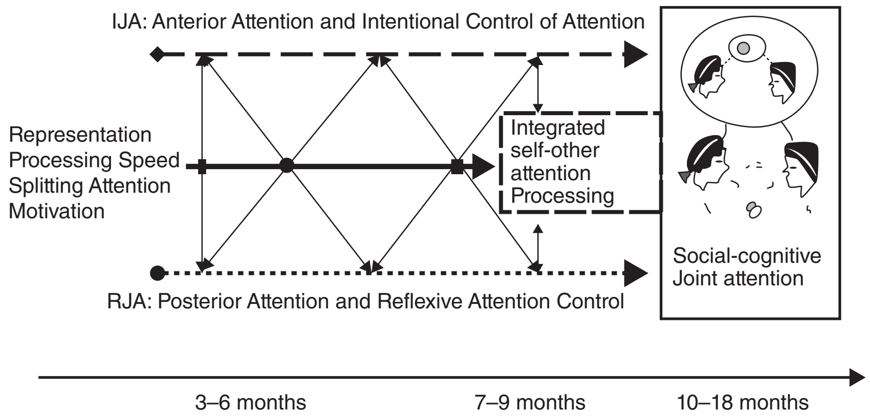

Figure 4.6 An illustration of the parallel distributed information processing system model of joint attention and social cognition. In this model, different types of lines depict the multiple paths of joint attention development. The posterior attention system path associated with RJA development is illustrated with a dotted line and the anterior attention system path associated with IJA development is illustrated with a dashed line. The central solid line in the figure depicts the developments of other processes during infancy that influence joint attention development, such as representational ability, speed of processing, motivation, and executive attention control, as well as each other, during infancy. The diagonal arrows connect all paths throughout early development. This reflects the dynamic and coactive nature of joint attention development, whereby the maturation of attention, cognitive, and affective systems interact in reciprocal cause and effect relations with experience, including the experiences children create for themselves through their own actions. Finally, the development of integrated self and other attention processing is considered to be a social attention executive function of the anterior system that emerges in the 4- to 9-month period. This is represented by the box. The capacity to integrate and share overt aspects of attention provides a foundation for the ability to share covert aspects of attention, such as representations, and social cognition. *Source:* From P. Mundy & L. Newell, Attention, joint attention and social cognition, *Current Directions in Psychological Science*, *16*, p. 272, 2007.

which young children execute joint attention behaviors. Gredebäck, Fikke, and Melinder (2010) reported longitudinal data across assessments at 2, 4, 6, and 8 months of age, whereupon infants displayed a significant linear increase from age to age in the tendency to shift gaze in response to the line of regard of a tester. More pertinent, though, was the observation that infants displayed a significant linear decrease in their latency to follow gaze, from about 3.5 seconds at 2 months to 1.5 seconds at 8 months. We have observed a similar longitudinal decrease in RJA latency, from approximately 2 seconds at 9 months to 0.8 seconds at 18 months (Vaughan Van Hecke et al., 2012). Moreover, 9-month-olds displayed a reduction in latency with practice across four RJA trials (Figure 4.7).

A definitive interpretation of the causes of the decrease in latency in RJA in these studies is not yet possible. Nevertheless, these patterns of results are consistent with the notion that execution of joint attention behaviors becomes more rapid, efficient and, perhaps, automated, across the first two years of life in typical development. One possibility is that this is due to practice effects interacting with interconnectivity within the frontal and posterior joint attention network that has been observed to develop in the first years of life (Elison et al., 2013).

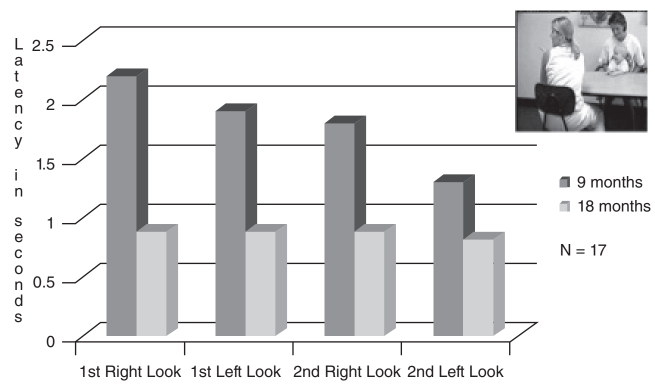

Figure 4.7 An illustration of the decrease in response latency to left and right RJA trials on the Early Social-Communication Scales (Mundy, Hogan, & Doehring, 1996) between 9 and 18 months of age. Also illustrated is the decrease in response latency across a sequence of RJA trials exhibited by infants at 9 months of age. See footnote 1.

In summary, the PDPM model of joint attention holds that integrated and, at times, collaborative processing of information about one's own focus of attention and the attention of other people is a necessary faculty for competent human social engagement, social learning, and social communication. In addition, joint attention is a form of parallel processing that occurs across a distributed cortical network. Practice with joint attention in infancy contributes to the development of an efficient distributed neural network that plays a crucial role in human social cognition. The potential role of parallel and distributed processing in synthesis in human social cognition has previously been recognized (Decety & Sommerville, 2003; Keysers & Perrett, 2004). However, the developmentally primary role of joint attention in this synthesis is less well recognized.

Social Cognition and the PDPM of Joint Attention

Social-cognitive models often describe joint attention in terms of incremental stages of knowledge about the intentionality of other people. Baron-Cohen (1995) described a sequence of cognitive modules that included the *intentionality detector* (ID; i.e., a dedicated cognitive facility that attributes goal directed behavior to objects or people) and the *eye direction detector* (EDD; i.e., senses and processes information about eyes). These combine to form the *shared attention mechanism* (SAM), a cognitive module that represents self and other as attending to the same referent and attributes volitional states (intentionality) to direction of gaze of other people. As infancy ebbs the *theory of mind mechanism* replaces SAM and enables representation of the full range of mental states of others and enables us to make sense of others' behaviors.

Tomasello et al. (2005) more explicitly described joint attention development in terms of three stages of what infants know about other people. In the *understanding animate action stage*, 3- to 8-month-old infants can perceive contingencies between their own animate actions and emotions relative to the animate actions and affect of others. However, they cannot represent the internal mental goals of others that are associated with these actions. Next, in the *understanding of pursuit of goals* stage, 9-month-olds become capable of shared action and attention on objects (e.g., building a block tower with parents).

Tomasello et al. (2005) suggested that the *understanding of pursuit of goals* stage involves joint perception, rather than joint attention, because the social-cognitive capacity to represent others' internal mental representations necessary for true joint attention is not yet available. However, this ability emerges between 12 and 15 months in the *understanding choice of plans* stage. This stage is heralded when infants become truly active in initiating episodes of joint engagement by alternating their eye contact between interesting sights and caregivers (Tomasello et al., 2005). This shift to active alternating gaze indicates infants' appreciation that others make mental choices about alternative actions that affect their attention. Infants also now know themselves as agents that initiate collaborative activity based on their own goals. Hence, the development of true joint attention at this stage is revealed in the capacity to adopt two perspectives analogous to speaker–listener.

The capacity to adopt two perspectives is also assumed to be an intrinsic characteristic of symbolic representations. In this regard, Tomasello et al. (2005) raised a truly seminal hypothesis, that symbolic thought is a developmental transformation of joint attention. They argue that symbols themselves serve to socially coordinate attention so that the intentions of the listener align with those of the speaker. In other words, linguistic symbols both lead to and are dependent upon the efficient social coordination of covert mental attention to common abstract representations among people. This hypothesis fits well with the parallel and distributed processing model of joint attention, but the PDPM places it in a substantially different developmental framework.

The PDPM does not emphasize functional segregation of cognitive systems implicit to modular perspectives, but instead emphasizes the cortically multi-determined nature of human cognition because of the "massively parallel nature of human brain networks and the fact that function also emerges from the flow of information between brain areas" (Ramnani et al., 2004, p. 613). Furthermore, cognitive development need not be construed only in terms of changes in discontinuous stage knowledge. It can also be modeled as a continuous change in the speed, efficiency, and combinations of information processing that give rise to knowledge (Hunt, 1999). Specifically, the PDPM envisions joint attention development in terms of increased speed, efficiency, and complexity of processing of (1) internal information about self–referenced visual attention, (2) external information about the visual attention of other people, and (3) the neural networks that integrate processing of self-generated visual attention information with processing of information about the visual attention behavior of other people (Mundy & Newell, 2007).

Consequently, the notion that *true* joint attention does not emerge until requisite social-cognitive knowledge emerges at 12–15 months (Tomasello et al., 2005) is not germane to the PDPM. Rather, consistent with a growing empirical literature, the PDPM holds that the true joint processing of attention information begins to be practiced by infants by 3 to 4 months of age (D'Entremont, Hains, & Muir, 1997; Farroni, Massuccessi, & Francesca, 2002; Hood, Willen, & Driver, 1998, Morales et al., 1998; Striano, Reid, & Hoel, 2006; Striano & Stahl, 2005). Indeed, even the types of active alternating gaze behaviors thought to mark the onset of true joint at 12–15 months (Tomasello et al., 2005) develop no later than at 8–9 months of life, and quite possibly earlier (Mundy et al., 2007; Venezia et al., 2004).

Equally important, the PDPM assumes that joint attention is not replaced by the subsequent development of social-cognitive processes. Instead, joint attention is thought to remain an active system of information processing that supports cognition through adulthood (Mundy & Newell, 2007). As an example, recall the hypothesis that linguistic symbols enable the social coordination of covert attention to common mental representations across people (Tomasello et al., 2005). According to the PDPM, symbolic thinking involves joint attention but does not replace joint attention. Just as 12-month-olds can shift eye contact or use pointing to establish a common visual point of reference with other people, 4-year-olds can use symbols to establish a common reference to covert mental representations with other people. Symbolic representations are often, if not always, initially encoded during the joint processing of information about the overt attention of self and of others directed toward some third object or event (Adamson, Bakeman, & Dekner, 2004; Baldwin, 1995; Werner & Kaplan, 1963). The PDPM combines that hypothesis with the connectionist notion that “representations can take the form of patterns of activity distributed across processing units” that occurred during encoding (Munakata & McClelland, 2003, p. 415). Together these two ideas lead to the assumption of the PDPM that symbol acquisition incorporates the distributed activation of the joint self-attention and other-attention neural processing units, which were engaged during encoding, as part of their functional neural representational mappings. Hence, the distributed joint attention processing system may always be activated as a network encoding that contributes to the intersubjectivity (i.e., shared attention and meaning) of symbolic thought.

In infancy, the distributed joint attention processing system is initially effortful. However, thousands of episodes of practice allow the joint information processing of self–other attention to become efficient, less effortful, and even automatically activated in social engagement. As this occurs, joint attention becomes a social-executive subroutine that runs in support of symbolic thought, as well as that capacity to maintain a shared focus in social interactions and in social cognition (Mundy, 2003). The distributed neural activation patterns associated with joint attention are part of infants’ sense of developing sense of relatedness to others (Mundy & Hogan, 1994; Mundy, Kasari & Sigman, 1993). Moreover, the distributed neural activation associated with joint attention can be thought of as an enduring stratum of a more continuous spiral of human social-neurocognitive development that supports, if not enables, later emerging human symbolic, linguistic, and social cognitive facilities (Figure 4.8).

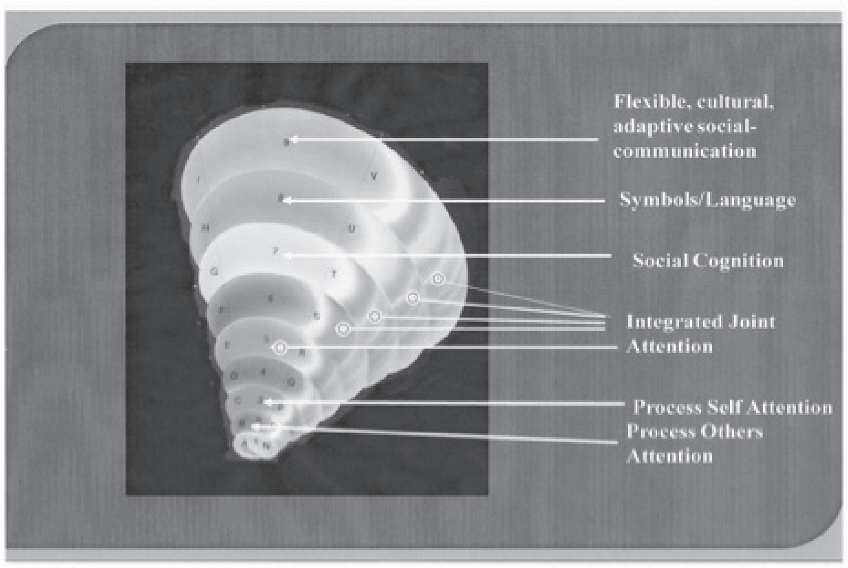

Figure 4.8 An illustration of the continuous information processing model of social attention, joint attention, and social-cognition. Here development is modeled as a spiral, in which the initial acquisition of the capacity for integrated processing of information about self- and other- attention (joint attention) remains an active but deeper layer of cognitive activity throughout life that supports symbolic thought, language, and cultural social exchange.

Inside-Out Processing and the Joint Attention PDPM

In addition to parallel and distributed processing, the PDPM may be distinguished from other models by its constructivist perspective on development. Rather than focusing on the development of knowledge about others, the PDPM gives equal footing to the significance of infants' development of their own intentional visual behavior in joint attention and social cognitive development (Mundy et al., 1993). The assumption here is that neonates and young infants receive greater quantities and fidelity of information about self-intended actions (e.g. active looking) through proprioception than they receive about other's intended actions through exteroceptive information processing. Thus, infants have the opportunity to learn as much or more about intentionality from their own actions as from observing the actions of others. A corollary of this assumption of the PDPM is that joint attention is an embodied form of cognition (Feldman & Narayanan, 2004). Its development is a constructivist process that involves self-perception as a foundation for the attribution of meaning to the perception of others' behaviors. We have referred to this as the inside-out processing assumption of the PDPM (Mundy & Vaughan, 2008).

The general tenor of this constructivist assumption is nothing new. Bates et al. (1979) suggested that a sense of self-agency was basic to joint attention. More generally, Piaget (1952) argued that infants do not learn through the passive perception of objects (or others) in the world. Rather, infants take action on objects and learn from their (causal) actions. They then modify their actions, observe changes in causal relations, and learn new things about the physical world. Thus, Piaget viewed the processing of self-initiated actions on objects as a singularly important fuel for the engines of cognitive development. The constructivist viewpoint is not only central to the PDPM, but it is also a mainstay of contemporary connectionist biological principles of typical and atypical neurocognitive development (e.g., Blakemore & Frith, 2003; Elman, 2005; Mareschal et al., 2007; Meltzoff, 2007; Quartz, 1999).

The vast number of functional neural connections that are made in early postnatal brain development are thought to be too numerous to be specified by genes alone. Instead, genes specify relatively wide channels of potential neurodevelopmental architecture (e.g., Quartz, 1999). Within these prescribed channels, the specifics of important functional connections in the developing nervous systems are sculpted by our experience. Since most of us experience relatively similar environments and experiences in early developmental life, brain organization displays significant similarities across most people (Mareschal et al., 2007). Greenough et al. (1987) referred to this gene–environment interaction in the ontogeny of neural connections as experience–expectant neurodevelopment. They also explicitly noted that infants' generation of actions, and observations of social reactions, likely play a role in experience-expectant processes specific to the neurodevelopmental basis of human social behavior (Cicchetti & Toth, 2009). So, just as Piaget envisioned that infants learn about the physical world from their self-generated actions on objects, it is reasonable to think that a significant portion of what infants learn about the social world comes from their self-generated actions with people. One type of self-generated action that may be developmentally key in this regard is active vision.

Active Vision and the Joint Attention PDPM

One of the first and most vitally informative types of actions infants take involves the self-control of their looking behaviors, or active vision. The science of vision has moved away from the study of seeing or passive visual perception to the study of looking or intentional, active vision and attention deployment (Findlay & Gilchrist, 2003). Active vision in infancy begins to develop at 3–4 months of age (e.g., Canfield & Kirkham, 2001; Johnson, 1990, 1995). It involves the goal-directed selection of information to process and can elicit contingent social behavior responses from other people, such as parental smiles, vocalizations, or gaze shifts. It also is one of the first types of volitional actions that infants use to control stimulation to self-regulate arousal and affect (Posner & Rothbart, 2007).

Vision and looking behavior have unique properties. Vision provides information regarding the relative spatial location of oneself and other people. Moreover, direction of gaze conveys the distal and proximal spatial direction of our attention to others, and vice versa. Comparable information on the spatial direction of attention is not as clearly available from the other senses. This is especially true in the first 9 months of life and for distal information. The importance of spatial visual information for the development of joint attention was emphasized by Butterworth and Jarrett (1991) in their influential article "What Minds Have in Common Is Space."

In some sense, primate eyes are specialized for *social* spatial attention processing (e.g., Tomasello, Hare, Lehman, & Call, 2006). Frontal binocular eye positions allow for enhanced spatial processing and depth of perception through parallax perception. Intricate musculatures allow for rapid visual focus on objects that are far or near. Equally important, precise information about the spatial direction of attention is available from human eyes because of the highlighted contrast between the dark coloration of the pupil and iris, versus the light to white coloration of the sclera. These observations have led to the suggestion that the ease of processing the direction of attention of other people's eyes contributed to the human phylogenetic and ontogenetic development of social cognition (e.g., Tomasello et al., 2006).

It is also the case, though, that these characteristics of the human eye allow the saccades of infants to be readily observed by other people. Consequently, infant saccades can effectively act as elicitors of contingent social feedback. When infants shift attention to an object, their parents may pick-up and show them the object. When infants shift attention to their parents' eyes, they may also receive a vocal, affective, or physical parental response. Thus, just as the characteristics of eyes make it easier for infants to perceive the attention of others, the signal value of eyes makes the active control of vision a likely nexus of infants' developing sense of agency. A corollary here is that a sense of visual self-agency may play a role in joint attention and social-cognitive development.

The notion that active vision has primacy in social development relates back to the time-honored observation that visual behavior is at least as important to human social development as physical contact (Rheingold, 1966; Robson, 1967). However, the contemporary literature on social-cognitive development emphasizes only the importance of the information infants gather from processing the visual attention of others (e.g., Johnson et al., 2005). It neglects the potential importance of the information infants process about their own active vision, and socially contingent responses.

Alternatively, the active vision assumption of the PDPM offers one plausible explanation for why activation of the frontal eye-fields (a cortical area involved in volitional saccadic control) is a consistent significant correlate of social-cognition in imaging studies (Mundy, 2003). This is because the volitional control of active vision, via the frontal eye fields, may be central to developing an integrated sense of the relations between self-attention and other-attention, which is fundamental to joint attention and subsequent social cognition. This hypothesis leads to the testable prediction that the frontal eye fields should be less active in social-cognitive processing in older congenitally blind individuals than in sighted individuals (Mundy & Newell, 2007). If true, this hypothesis may also help to explain some of the developmental commonalities observed for children with autism and blind infants (Bigelow, 2003; Hobson, Lee, & Brown, 1999).

DYNAMIC SYSTEMS AND THE JOINT ATTENTION PDPM

The PDPM emphasizes inside-out processing, constructivism, and the role of active vision in the development of joint attention. However, it does not maintain that the inside-out processing of self-attention is more important for social-cognitive development than outside-in processing of others' attention. This is because the PDPM holds that social meaning, and even conscious self-awareness, cannot be derived from processing either self-attention or others' attention in isolation (cf. Decety & Sommerville, 2003; Keysers & Perret, 2004; Vygotsky, 1962). Ontogeny may be best viewed as a dynamic system that, through interactions of multiple factors over time and experience, coalesce into higher order integrations, structures, and skills (e.g., Smith & Thelen, 2003). The development of joint attention, or the joint processing of the attention of self and other, is such a dynamic system. Indeed, the pertinence of joint attention for human development derives in no small part from the unique synthesis that arises from the rapid, parallel processing of self-attention and other-attention across distributed neural networks. Consequently, it is not possible to account for the role of joint attention in typical or atypical development with research or theory that focuses on only one of its elements in isolation.

The dynamic system of joint attention begins to synergize as frontal executive functions increasingly enable attending to multiple sources of information during infancy. According to one definition, executive functions involve the transmission of bias signals throughout neural networks to selectively inhibit comparatively automatic behavioral responses, in favor of more volitional, planned, and goal-directed ideation and action, in problem-solving contexts (Miller & Cohen, 2001). These bias signals act as regulators for the brain, affecting visual processes and attention, as well as other sensory modalities and systems responsible for task-relevant response execution, memory retrieval, emotional evaluation, and so forth. The aggregate effect of these bias signals is to guide the flow of neural activity along pathways that establish the proper mappings between inputs, internal states, and outputs needed to perform a given task more efficiently (Miller & Cohen, 2001). According to this definition, joint attention development may be thought of as reflecting the emergence of frontal bias signals that establish the proper mappings across (1) outside-in posterior cortical (temporal-precuneous) processing of inputs about the attention behaviors of other people; and (2) rostral-medial-frontal (BA 8–9, anterior cingulate) inside-out processing of internal states and outputs related to active vision. This mapping results in the integrated development of a distributed anterior and posterior cortical joint attention system.

It is conceivable that the early establishment of this mapping of the joint processing of attention is formative with respect to the shared neural network of representations of self and other, which Decety and Grezes (2006) suggested is essential to social cognition. It also may play a role in what Keysers and Perrett (2004) described as a Hebbian learning model of social-cognition. Neural networks that are repeatedly active at the same time become associated, such that activity (e.g., representations) in one network triggers activity in the other (Hebb, 1949). Keysers and Perrett suggested that *common* activation of neural networks for processing self-generated information and information about conspecifics is fundamental to understanding the actions of others. This Hebbian learning process is fundamental to the hypothesized functions of simulation (Gordon, 1986) and mirror neurons (Decety & Sommerville, 2003; Williams, 2008) that are commonly invoked in current models of social-cognitive development.

The PDPM is consistent with these interrelated ideas and suggests that Hebbian mapping in social cognition begins with integrated rostral medial frontal processing of information about self-produced visual attention and posterior processing of the attention of others. Moreover, the PDPM specifically operationalizes the study of development of this dynamic mapping system, in terms of psychometrically sound measures of early joint attention development (Mundy et al., 2007). Indeed, IJA assessments may be relatively powerful in research on social cognitive development and developmental disorders because they measure variance in the whole dynamic system, rather than any one of its parts alone.

Once well practiced, the joint processing of attention information requires less mental effort. As the basic joint attention process is mastered and its effort to engage goes down, it can become integrated as an executive function that contributes to the initial development and increasing efficiency of social-cognitive problem solving. Thus, joint attention development may be envisioned as shifting from learning to do joint attention in the 6 to 9 months to learning from joint attention in the second year of life (Mundy & Vaughan, 2008; Figure 4.9). In the learning from phase, the capacity to attend to multiple sources of information in triadic attention deployment becomes more common (Scaife & Bruner, 1975). Triadic attention contexts provide infants with rich opportunities to compare information gleaned through processing internal states associated with volitional visual attention deployment and the processing of the visual attention of others in reference to a common third object or event. Through simulation (Gordon, 1986) infants may begin to impute that others have intentional control over their looking behavior that is similar to their own.

The role of simulation in the *learning-from phase* of joint attention development is well illustrated by a recent sequence of elegant experimental studies (Brooks & Meltzoff, 2002). Often, 12-month-olds follow the gaze direction of testers even if their eyes are closed. After 12 months, though, infants discriminate and follow the gaze of testers whose eyes are open but not closed. This suggests that infants' understanding of the meaning of the eye gaze of others may improve in this period, leading older infants to inhibit looking in the eyes-closed condition.

To examine this interpretation, Meltzoff and Brooks (2008) conducted an experimental intervention. They provided 12-month-olds with the experience of blindfolds that occluded their own looking behavior. After gaining that experience, 12-month-olds did not follow the head turn of blindfolded testers, but did follow the head turn and gaze of nonblindfolded testers. Meltzoff and Brooks also provided 18-month-olds with experience with blindfolds that looked opaque but were transparent when worn. After this condition, the 18-month-olds reverted to following the gaze of blindfolded social partners. These data strongly suggest that the infants demonstrated inside-out learning and constructed social-cognitive awareness about others' gaze based on the experience of effects of blindfolds on their own active vision.

In sum, infant translational research proposed that a foundational system of integrated attention to self and other, supported by a dynamic, distributed neural network, provides for enhancements in social communication, social learning, and social cognition in typical development. The ability to utilize this integrated, or joint, attention to share experiences with others develops in early infancy, and transitions from a phase of learning-to utilize joint attention to learning-from joint attention in toddlerhood, childhood, and even beyond. Individual differences in the capacity to utilize joint attention likely play a role in the range of

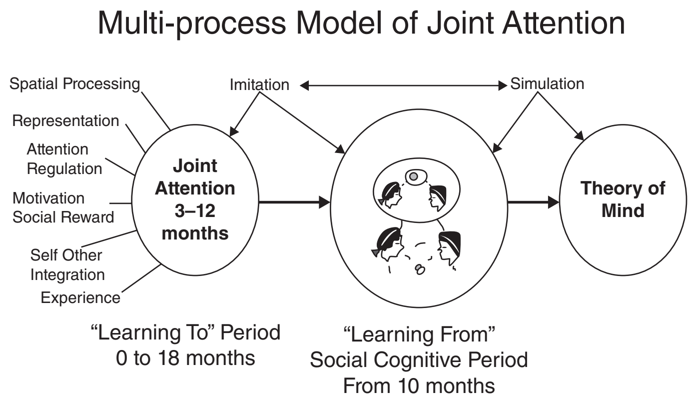

Figure 4.9 In the first year, the development of joint attention involves the "learning-to" phase. This period comprises the integration of executive, motivational, and imitative processes to support the routine, rapid, and efficient (error-free) execution of behavioral patterns, which enable infants' coordination of overt processing of aspects of visual self-attention, with processing of the social attention of other people. In the latter part of the first year and the second year, infants can better monitor their own experiences and integrate them with information about social partners during joint attention events. This provides a critical multimodal source of information to the infants about the convergence and divergence of self- and other-experience and behavior during sharing information in social interactions. Theoretically, this provides the stage for the "learning-from" phase of joint attention development. In this stage, infants can control their attention to self-organize and optimize information processing in social learning opportunities. The integration of anterior and posterior self–other attention processing (Figure 4.5) provides a neural network that enriches encoding in social learning. The internalization of the overt joint processing of attention to the covert joint processing of attention to representations is part of an executive system that facilitates symbolic development and the social cognition. Both symbolic thought and social cognition may be characterized by a transition from learning to socially coordinate overt attention to the capacity to socially coordinate covert mental representations of the attention of self and others.

social-emotional and social-cognitive skill present in the population. The next natural area of inquiry, then, involves how difficulties with joint attention play a cardinal role in a population in the extreme range of deficits in social abilities: individuals with ASD.

JOINT ATTENTION AND DEFINING THE SOCIAL DEFICITS OF ASD

The recognition of the centrality of joint attention impairment in the development of ASD followed from the growing understanding of how and when typical infants develop the ability to share experiences with other people (Bates et al., 1979; Bruner, 1975; Rheingold et al., 1976; Trevarthen, 1979; Werner & Kaplan, 1963). While other domains of social behavior, such as imitation, face processing, empathy, theory of mind, and pragmatic communication skills, are prominent in the literature (Travis & Sigman, 1998), none have had the impact on understanding the nature of ASD, its diagnosis, or its treatment that can be claimed for the study of joint attention (e.g., Bruinsma et al., 2004; Charman, 1997; Dawson et al., 2004; Kasari et al., 2006, 2008; Mundy & Crowson, 1997; Mundy et al., 2009; Sigman & Ruskin, 1999).

It was Frank Curcio (1978) who first documented joint attention disturbance in individuals with ASD. He noted that 50% of a sample of elementary school–age children with ASD observed in classrooms systematically used eye contact and conventional gestures to express their requests. However, few, if any, children with ASD displayed evidence of the use of eye contact or gestures to initiate joint attention bids or nonverbal declaratives. Curcio concluded that impairments in the capacity to initiate joint attention and declarative communicative functions could be central to the nature of the social impairments of ASD. Subsequent studies indicated that Curcio was correct (e.g., Charman, 2004; Dawson et al., 2004; Loveland & Landry, 1986; Mundy et al., 1986; Sigman & Ruskin, 1999; Wetherby & Prutting, 1984).

In work in the laboratory of Marian Sigman at UCLA, samples of children with ASD were compared with mental age, chronological age, and IQ-matched samples of 4- to 7-year-old children with intellectual disabilities and samples of mental age-matched children with typical development. These studies indicated that children with ASD displayed deficits in joint attention in interactions with unfamiliar testers (Mundy et al., 1986), as well as parents, compared with both control groups (Sigman et al., 1986). Moreover, just as Curcio observed, children with

ASD displayed quantities and qualities of communication bids to request objects and turn-taking opportunities with social partners that were comparable to those observed in the control sample with intellectual disabilities (ID). These case-controlled studies indicated that children with ASD did not display pervasive differences in eye contact or social-communication behaviors relative to children with ID, but rather a more nuanced pattern of syndrome-specific strengths and weaknesses in their social behaviors. They displayed comparable levels of eye contact in requesting and turn-taking social interactions. However, an eye contact disturbance specific to ASD was clearly manifested in their diminished use of alternating gaze to spontaneously initiate sharing of experience of a mechanical toy with the tester. This type of alternating gaze behavior is illustrated in Figure 4.1.

We cannot yet definitively describe why a child does or does not engage in IJA during a social interaction. Nevertheless, ESCS testers often arrived at the impression that IJA behaviors signal a child's desire (motivation) or goal (intent) to share the experience of an object or event, or spontaneously elicit attention to the child's own experience of an object or event (Figure 4.1). Hence, it was not too surprising to find that higher or lower frequencies of alternating eye contact in young children, with or without ASD, were significantly related to parents' independently assessed perceptions of their child's social relatedness (Mundy et al., 1994). These observations raised the possibility that diminished IJA was central to what Kanner perceived as the cardinal impairment in relatedness and positive affective contact with others in ASD (e.g., Mundy & Sigman, 1989).

The Social-Motivation Model and Joint Attention in ASD

The idea that IJA was related to a disturbance in positive social-affective contact in autism was more directly supported by research in the early 1990s that showed that about 60% of the IJA bids displayed by typical infants and children with intellectual disabilities involved the conveyance of positive affect (Kasari, Sigman, Mundy, & Yirmiya, 1990; Mundy, Kasari, & Sigman, 1992). However, positive affect was much less frequently part of the IJA behaviors of children with autism (Kasari et al., 1990). It was not the case, though, that children with ASD displayed significantly lower positive affect in requesting or turn–taking interactions. Hence, it was unlikely that the diminished positive affect in joint attention reflected a general aversion to social interactions. More recently, it has come to light that the onset of the systematic conveyance of positive affect as part of IJA bids begins to develop early in life, at about 8 to 10 months of age (Venezia, Messinger, Thorp, & Mundy, 2004) and that this type of anticipatory smiling in joint attention is associated with social outcomes in typical development (Parlade, Messinger, Delgado, Kaiser, Van Hecke, & Mundy, 2009). Thus, joint attention impairments reflect what are likely to be early arising deficits in the tendency of children with ASD to socially share positive affect. This in turn may involve a disturbance in their early appreciation of the positive social *value* of shared attention. That is to say, motivation factors or sensitivity to reward value of social gaze may play a role in joint attention disturbance in ASD (Dawson, Bernier, & Ring, 2012; Mundy, 1995).

Joint Attention and the Social-Cognitive Model of ASD

In a similar timeframe, other translational infant research groups in London began to translate Wimmer & Perner's basic false belief developmental paradigms to the study of ASD. This led to another sequence of seminal observations regarding the defining features of social impairments in ASD. Children with ASD appeared to have more difficulty with the development of social-cognition than other aspects of cognitive development (e.g., Baron-Cohen, Leslie, & Frith, 1985; Frith, 1989; Leslie & Happé, 1989).

Thus, the parallel observations of deficits in joint attention development and theory of mind development in ASD during the mid-1980s provided the first empirical, albeit indirect, link between these two domains of development. Subsequently, the social cognitive view of ASD and typical social development became so compelling in the literature that joint attention disturbance began to be interpreted as a manifestation of social cognitive impairment in ASD (Baron-Cohen, 1989; Leslie & Happé, 1989). In developmental psychopathology, these ideas converged to form the social cognitive model of joint attention disturbance in ASD, which held that the social cognitive understanding that people intentionally share information, was a necessary precursor of joint attention (Tomasello, Carpenter, Call, Behne, & Moll, 2005), and that impairments in a social cognitive module explained the cause of joint attention impairment in ASD (Baron-Cohen, 1989).

The Disassociation of IJA and RJA in ASD

However, a potential problem for the social cognitive model is that both RJA and IJA development were assumed to be equally dependent on social cognition. But IJA and RJA appeared to be dissociated in development. Thus one factor, such as social cognition, might not be adequate to explain all facets of joint attention development or its impairment in ASD. Both RJA and IJA are useful in the early identification and diagnosis of ASD (e.g., Lord et al., 2000; Stone, Coonrod, & Ousley, 1997). However, RJA impairments are less evident for children with more advanced levels of cognitive development (Mundy et al., 1994; Figure 4.10). Indeed, across studies of different age groups of children, there is at best inconsistent evidence of a robust syndrome specific impairment in the ability to process the direction of gaze or respond to joint attention in people with ASD (Nation & Penny, 2008). On the other hand, IJA deficits are observed in children with ASD from preschool through adolescence, *and* IJA is a better discriminator of children with ASD relative to children with other developmental disorders (e.g., Charman, 2004; Dawson et al., 2004; Hobson & Hobson, 2007; Mundy et al., 1986; Sigman & Ruskin, 1999). The correlates of IJA and RJA also diverge as much as they converge in studies of ASD. Both IJA and RJA are related to executive inhibition and language development in ASD (Bono, Daley, & Sigman, 2004; Dawson et al., 2002, 2004; Griffith et al., 1999; Sigman & McGovern, 2005). However, to our knowledge, only IJA is significantly associated with individual differences in social and affective symptom presentation (Charman, 2004; Kasari et al., 1990; Kasari et al., 2007; Lord et al., 2003; Mundy et al., 1994; Naber et al., 2008; Sigman & Ruskin, 1999).

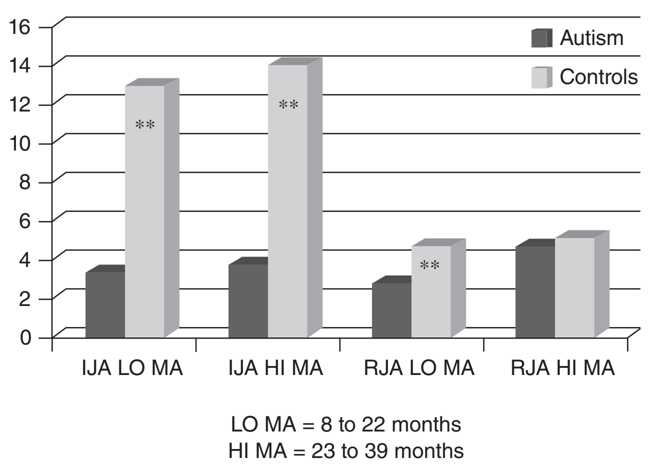

Figure 4.10 Illustration of the moderating effect of mental age on diagnostic group differences on RJA versus IJA. *Source:* Reported in P. Mundy, M. Sigman, & C. Kasari, Joint attention, developmental level, and symptom presentation in children with autism, *Development and Psychopathology, 6,* 389–401, 1994.

This literature emphasizes that joint attention deficits are neither absolute nor uniform in ASD, and the impairments of IJA and RJA likely constitute different developmental processes that are vital to symptom presentation in the syndrome. Moreover, of the two, deficits in initiating joint attention behavior appears be the more pathognomonic feature of ASD (Mundy, 1995). Observations from intervention research also emphasize that ASD is a disturbance of the spontaneous generation of social behaviors, as much as or more than a disturbance of perception and response to the social behaviors of others (Koegel et al., 2003). A similar interpretation is suggested by recent research with infant siblings of children with ASD (Zwaigenbaum et al., 2005). Indeed, the centrality of initiating deficits, especially IJA, was highlighted in the *DSM-IV*, where “a lack of spontaneous seeking to share enjoyment, interests, or achievements with other people, (e.g., by a lack of showing, bringing, or pointing out objects of interest to other people)” was described as one of the primary social symptoms of ASD (APA, 1994, p. 75). Unfortunately, the significance of the impairment of the spontaneous generation of behavior, and specifically initiating joint attention, is still not fully appreciated in the field. Consequently, the latter is not as clearly emphasized in *DSM-5* (APA, 2013) as it was in *DSM-IV* (APA, 1994). Nevertheless, the gold standard research-based diagnostic observation instrument, the Autism Diagnostic Observation Schedule-2nd Edition (ADOS-2: Lord et al., 2012), continues to recognize the primacy of IJA symptoms. Measures of both IJA and RJA are used in Module 1 diagnostic algorithms for the youngest children. However, Module 2, for older or more linguistically advanced children, only includes IJA measures in its diagnostic criteria (Lord et al., 2012).

Evidence of a developmental dissociation between IJA and RJA is also apparent in studies of typical infant development. Frequency measures of IJA and RJA are characterized by different growth patterns, and these domains display weak to non-significant correlations in infant development (e.g., Meltzoff & Brooks, 2008; Mundy et al., 2007; Sheinkopf et al., 2004; Slaughter & McDonald, 2003). They also have different patterns of correlations with childhood IQ (Ulvund & Smith, 1996), frontal brain activity (Caplan et al., 1993; Mundy et al., 2000), reward-based behavioral goal-inhibition and self-monitoring behaviors (Nichols et al., 2005), attention related self-regulation (Morales et al., 2005), and attachment (Claussen, Mundy, Malik, & Willoughby, 2002). These observations imply that the nature of the differences, as well as commonalities, between IJA and RJA may be a key to conceptualizations of the joint attention impairments of ASD.

Specific Effects on Initiating Joint Attention in ASD

It is essential to be precise about the nature of the behavioral expression of IJA impairments in ASD, which are often equated with problems with pointing and showing gestures. However, diminished alternating gaze behavior (Figure 4.1) is a more powerful measure of IJA impairment in ASD. This type of measure was superior to pointing and showing, and correctly identified 94% of 54 preschool children with ASD, mental retardation, and typical development (Mundy et al., 1986). Others have observed that IJA measured with the Early Social-Communication Scales (ESCS; Seibert, Hogan, & Mundy, 1982) had a sensitivity of 83–97% and a specificity of 63–67% in discriminating 3- to 4-year-olds with ASD from controls (Dawson et al., 2004). Recent research indicates that most of the variance in ESCS-IJA scores is carried by alternating gaze behavior (Mundy et al., 2007). The IJA alternating gaze of 2-year-olds also predicts 4-year-old symptom outcomes in children with ASD (Charman, 2004) as well as social cognition in typically developing 4-year-old children (Charman et al., 2000).

These developmental and measurement details are important for models of joint attention disturbance in ASD. Often joint attention problems are viewed as growing out of developmental antecedent or successor processes that are considered to be more fundamental. A nonexhaustive list here includes affective processes, reward-sensitivity, executive attention control, social orienting, identification, imitation and mirror neurons, intersubjectivity, and most prominently social cognition (e.g., Baron-Cohen, 1989; Charman, 2004; Dawson et al., 2004; Mundy et al., 1986; Williams, 2008). This reductionism has lead to a paradox where joint attention deficits are viewed as pivotal to ASD but also as an outgrowth of more basic processes. Charman (2004) recognized this paradox in noting that we often think of joint attention not as "a starting point [for ASD], but merely a staging post in early social communicative development, and hence a 'postcursor' of earlier psychological and developmental processes . . . [which may] underlie the impaired development of joint attention skills in autism" (p. 321).

There are at least three problems with this perspective. First, as previously noted, stable individual differences in IJA alternating gaze are well established by 8 to 9 months in typical development (Mundy et al., 2007; Venezia et al., 2004), and the onset of cortical control of alternating gaze likely begins between 4 to 6 months of age (Mundy, 2003; Striano & Reid, 2006). Joint attention precursors would need to be present prior to this time. Second, there is little evidence that the association of joint attention with the etiology or outcomes of ASD is mediated by more basic antecedent or successor processes. Dawson et al. (2004) observed that neither social-orienting measures nor empathy measures could account for relations between IJA and language development in a large sample of children with ASD. Joint attention disturbance in ASD also cannot be explained in terms of affect regulation or social relatedness measured with attachment measures (Capps, Sigman, & Mundy, 1994; Naber et al., 2008). Moreover, joint attention accounts for significant portions of variance in the language, symbolic play, and symptom development of children with ASD above and beyond variance associated with executive functions, imitation, knowledge about others' intentions, or global measures of mental development (e.g., Charman, 2004; Kasari et al., 2007; Naber et al., 2008; Roeyers, Van Oost, & Bothutne, 1998; Rutherford, Young, Hepburn, & Rogers, 2007; Sigman & Ruskin, 1999; Smith, Mirenda, & Zaidman-Zait, 2007; Thurm, Lord, Lee, & Newschaffer, 2007; Toth, Munson, Meltzoff, & Dawson, 2006).

A third issue is that precursor and successor process hypotheses rarely account for the dissociation of IJA and RJA (Mundy et al., 2007). Social-cognitive hypotheses suggest that RJA and IJA should be highly related because they are precursors of a common mentalizing ability involved in perceiving the intentions of others (e.g., Baron-Cohen, 1995; Tomasello, 1995). Executive attention or social-orienting hypotheses don't explicitly account for why IJA deficits are more pervasive than RJA deficits even though both ostensibly involve comparable attention inhibition and attention reorienting processes (e.g., Dawson et al., 1998; Mundy & Burnette, 2005). Imitation and mirror neuron theory emphasizes the role of deficits in processing and responding to the behavior of other people in the development of ASD (e.g., Williams, 2008). Hypothetically, though, this should be more related to responsive joint attention than the spontaneous initiation of joint attention bids. Why, then, do IJA deficits appear to be the more robust form of joint attention disturbance in ASD than RJA deficits? An answer may be perceived from a constructivist vantage point on joint attention and human social learning (e.g., Bruner, 1975, 1995).

In light of the assumption that joint attention is basic to early learning, reconsider the observation that IJA and RJA dissociate in development. Theory and research suggest that this occurs because these forms of joint attention involve functions of two distinct neural networks that support attention development (Mundy & Newell, 2007). In conjunction with this idea, note that parallel and distributed cognitive theory suggests that learning occurs best in the context of the simultaneous activation of multiple neural networks during encoding (e.g., Munakata & McClelland, 2003; Otten, Henson, & Rugg, 2001). Taken together, these ideas raise two hypotheses. First, joint attention may involve the early development of a form of social information processing across multiple distributed neural networks. Second, ASD may be characterized by a developmental impairment of distributed neural connectivity, and an early disturbance of the cortically distributed joint attention network is a characteristic of the developmental etiology of many, if not all, children with ASD. The next, and final, section of this chapter will explore this second hypothesis, and its implications, in more detail.

APPLYING THE JOINT ATTENTION PDPM TO ASD

Neural Connectivity and Activity-Dependent Genes in ASD

Assumptions of the PDPM bridge theory on the development of joint attention with phenomena observed in other disciplines of research with ASD. Several of these will be briefly considered in this final section of the chapter. The first of these involves links with theory and research on neural connectivity impairments in ASD.

Over the last 10 years, several research groups have suggested that problems in functional connectivity between brain regions contribute to ASD (e.g., Courchesne & Pierce 2005; Geschwind & Levitt, 2007; Horwitz, Rumsey, Grady, & Rapoport, 1988; Just, Cherkassky, Keller, & Minshew, 2004; Lewis & Elman, 2008; Wickelgren, 2005). However, rather than specific to ASD, impaired connectivity may be central to many forms of intellectual disability and developmental disorders (Dierssen & Ramakers, 2006). So how do neurodevelopmental connectivity impairments lead to the specific social symptom impairments of ASD, and how are these different from the connectivity impairments that characterize other developmental disorders?

One possibility is that intellectual disability may be associated with connectivity impairments within proximal brain networks, but that ASD may be characterized by more distal connectivity problems (Courchesne & Pierce, 2005; Lewis & Elman, 2008). Indeed, several studies suggest that distal connectivity problems between frontal and temporal-parietal networks may be especially prominent in ASD (Cherkassky, Kana, Keller, & Just, 2006; Courchesne & Pierce, 2005; Murias,Webb, Greenson, & Dawson, 2007; Wicker et al., 2008). The PDPM offers a moderately explicit developmental account of how the impairment of distal frontal-parietal pathways may have an early and robust effect specific to a disturbance of joint attention and related social symptoms of ASD, such as a lack of spontaneously sharing experiences with other people. The PDPM's focus on the fundamental relations between the joint processing of attention information, learning, and symbolic development also provide a means for understanding why variations in the strength of the disturbance of anterior-posterior connectivity could contribute to phenotypic variability in ASD, such as the co-occurrence of intellectual disability or specific language impairments.

The connectivity assumptions of the PDPM also lead to the prediction that differences in the development of joint attention in typical and atypical children should be associated with measures of synchrony or coherence in cortical activity. There is some support for this, but currently available data are no more than suggestive in this regard (Mundy et al., 2000, 2003). Nevertheless, the PDPM offers a conceptual framework that emphasizes the benefits of a multidisciplinary approach to neurodevelopment, attention, and connectionist network models of development and ASD. This emphasis is in line with the recent call for the multidisciplinary examination of EEG or imaging connectivity/coherence in developmental and intervention studies of ASD (Cicchetti & Toth, 2009; Dawson, 2008).

It also may be that intellectual disability is associated with impairments of prenatal neural connectivity that are less activity dependent, but that ASD involves a greater degree of postnatal connectivity impairments that are more activity dependent (Morrow, Yoo, Flavell, Kim, & Lin, 2008). Morrow et al. recently observed several genome deletions in families of children with ASD. The expression of three genes associated with the two largest deletions (c3orf58, NHE9, and PCDH10) is regulated by neuronal activity. From this observation, Morrow et al. (2008) reasoned that defects in activity-dependent gene expression may be a cause of cognitive deficits in ASD. They note that these genes likely have a defined temporal course of greater or lesser vulnerability to atypical expression, depending on the timing and quality of the young child's postnatal activity and experience dependent processes.

The PDPM proposes that problems with initiating joint attention activity may be especially key to understanding activity dependent alterations of gene expression associated with ASD. Some evidence consistent with this proposition stems from the observation that the behavior of children with ASD may affect and modify the attempts of caregivers to scaffold the development of joint attention in their children (Adamson, McArthur, Markov, Dunbar, & Bakeman, 2004). If the PDPM is correct in this regard, it will be important to build a better understanding of genetic influences on the typical range of expression of individual differences in IJA in infant development. Little if any information currently exists on this topic. Fortunately, the recent observation of a surprising degree of longitudinal stability of individual differences, in a sample of 100 typical infants (Mundy et al., 2007), suggests that behavioral or metabolic genetic methods may be brought to bear in large-scale studies of the typical development of infant joint attention.

Visual Attention Control and Joint Attention in ASD

Complementary to genetic factors, the work of several research groups indicates that the basic mechanism of visual control may play a role in ASD (Brenner, Turner, & Muller, 2007; Johnson et al., 2005; Landry & Bryson, 2004). Brenner et al. (2007) noted that one of the essential issues for this line of research is to understand precisely, "how an ocular-motor system that is over-specialized for certain tasks and under-specialized for others early in life might affect later development in [social] domains such as joint attention" (p. 1302). The PDPM offers a guide in this regard. First, it encourages the research community to recognize the possibility that joint attention may not be a later development but one that begins as part of the development of volitional visual attention control by the fourth month of life. In addition, the PDPM provides a means for understanding how significantly altered early visual preferences could have a cascading effect on the development of intentional joint attention and ASD (Mundy, 1995). In this regard, consider two recent studies.

McCleery et al. (2007) observed that magnocellular visual processing may be atypically enhanced in a sample of 6-month-old infant siblings of children with autism. Similarly, Karmel et al. (2008) observed visual attention patterns that are consistent with a magnocellular bias in 6-month-olds in neonatal intensive care who later received the diagnosis of autism at 3 years of age. The magnocellular visual system contributes to orienting based on movement and contrast-sensitivity related to small achromatic differences in brightness. This system dominates early visual orienting. However, by 2 to 4 months of age, visual orienting is increasingly influenced by the parvocellular system, which contributes to orienting based on high-resolution information about shape or low-resolution information about color and shades of gray. Karmel et al. (2008) and McCleary et al. (2007) raised the possibility that a delay in the developmental shift from the magnocellular to parvocellular visual systems could alter what children with ASD choose to attend to early in life.

Hypothetically, the maintenance of a magnocellular bias may lead to a relatively long standing visual preference for stimuli or objects characterized by movement or achromatic contrasts, such as surface edges, power lines, spinning objects, the outlines of faces, or mouth movement. Reciprocally, the decreased influence of the parvocellular system could lead to developmental delays in the emergence of a visual attention bias to targets that are socially informative but involve differentiation based on high resolution of shape and color information, such as distal processing of eyes and facial expressions. Thus, the alteration of visual preferences during early critical periods of development could degrade the establishment of the dynamic system of internal information processing about active looking, relative to contingent social feedback, and information about the attention of other people (Mundy, 1995; Mundy & Burnette, 2005). Moreover, if magnocellular guidance bias and connectivity impairments are orthogonal processes, combinations of varying levels of their effects could present as phenotypic differences in joint attention processing and social symptom expression in ASD.

Joint Attention, Learning, and Interventions for ASD

The assumptions of the PDPM may also shed light on how joint attention serves as a pivotal skill in intervention, and as a foundation for the development of social cognition, symbolic thought, knowledge of intentionality, and social learning. First, the PDPM may help to explain why joint attention is a pivotal skill in early intervention for children with autism (Bruinsma, Koegel, & Koegel, 2004; Charman, 2004; Mundy & Crowson, 1997). Improvements in pivotal skills, by definition, lead to positive changes in a broad array of other problematic behaviors. According to the PDPM, joint attention is a pivotal skill in autism because its improvement has multiple effects on social learning. Recall that joint attention facilitates the self-organization of information processing to optimize incidental, as well as structured, social learning opportunities (Baldwin, 1995). Hence, impairment in joint attention may be viewed as part of a broader social-constructivist learning disturbance in autism. By the same token, effective intervention likely improves social constructivist learning in autism.

Small and large-scale trials have shown that joint attention can be improved with intervention for ASD (Table 4.1), and joint attention improvement has collateral

TABLE 4.1 Behavioral Intervention Studies With Effects on Joint Attention in Children With ASD[1]

Study	Intervention	Design	Participants in experimental treatment group (number/age)	JA outcomes
Small studies (fewer than 15 participants in experimental treatment group)				
Aldred, Green, and Adams (2004)	Developmental communication intervention (Aldred, Pollard, Phillips, & Adams, 2001)	RCT (vs. routine community care control)	14/2–5 yrs.	No change in CJA
Baker (2000)	Thematic ritualistic play intervention	MBL by participants	3/5–6 yrs.	Increase in CJA
Cheng and Huang (2012)	Joint Attention Skills Learning (JASL) virtual reality system/tool	MBL by participants	3/9–12 yrs.	Increase in IJA
Ezell et al. (2012)	Imitation	RCT (vs. Contingently Responsive Play control)	10/4–6 yrs.	Increase in IJA and RJA
Field et al. (1997)	Touch therapy	RCT (vs. non-therapeutic touch control)	11/mean 4 yrs., 6 mo.	Increase in RJA and IJA
Hwang and Hughes (2000)	Social interactive training: Following child, imitation, natural reinforcement	MBL by participants	3/2–3 yrs.	Increase in IJA
Ingersoll and Schreibman (2006)	Reciprocal imitation training	MBL by participants	5/2–3 yrs.	Increase in RJA; Mixed results for IJA
Ingersoll (2012)	Reciprocal imitation training	RCT (vs. community treatment control)	14/2–4 yrs.	Increase in IJA
Isaksen and Holth (2009)	Reinforcement, prompting, modeling	MBL by participants	4/3–5 yrs.	Increase in IJA and RJA
Jones, Carr, and Feeley (2006)	Pivotal response training; discrete trial	MBL by behaviors and participants	5/2–3 yrs.	Increase in IJA and RJA
Jones and Feeley (2007)	Pivotal response training; discrete trial; parent training	MBL by behaviors and participants	3/3–4 yrs.	Increase in IJA and RJA
Jones (2009)	Pivotal response training: modeling, prompting	MBL by behavior	2/3–5 yrs.	Increase in IJA
Klein, MacDonald, Vaillancourt, Ahearn, and Dube (2009)	Reinforcement	MBL by participants	3/4–6 yrs.	Increase in RJA
Krstovska-Guerrero and Jones (2013)	Direct instruction of smiling and eye contact, prompting, reinforcement	MBL by participants and behaviors	3/2–4 yrs.	Increase in IJA and RJA
Lawton and Kasari (2012)	JASP/ER: Joint Attention symbolic play engagement and regulation intervention; teacher implemented	RCT (waitlist control)	9/3–5 yrs.	Increase in IJA
MacDuff et al. (2007)	Auditory scripts, Reinforcement	MBL by participants	3/3–5 yrs.	Increase in IJA
Martins and Harris (2006)	Reinforcement	MBL by participants	3/3–4 yrs.	Increase in RJA; No change in IJA
Naoi et al. (2008)	JA reinforcement, modeling, preferred objects	MBL by participants	3/5–8 yrs.	Increase in IJA
Pierce and Schreibman (1995)	Pivotal response training; peer implemented	MBL by participants	2/10 yrs.	Increase in CJA
Rocha, Schreibman, and Stahmer (2007)	Parent training: discrete trial, pivotal response training	MBL by participants	3/2–4 yrs.	Mixed results for IJA and RJA
Rogers et al. (2006)	Early Start Denver Model (ESDM)	RCT (vs. prompts for restructuring oral muscular phonetic targets (PROMPT) control); MBL for participants and behaviors	5/2–5 yrs.	Mixed results for IJA and RJA for both interventions
Salt et al. (2002)	Scottish Center for Autism treatment program: Social developmental naturalistic intervention	Treatment (vs. waitlist control, not randomized)	14/3–4 yrs.	Increase in IJA and RJA (collapsed)
Schertz and Odom (2007)	Joint attention mediated learning (JAML) intervention (Schertz, 2005)	MBL by behaviors	3/1–2 yrs.	Mixed results for IJA and RJA
Schertz, Odom, Baggett, and Sideris (2013)	Joint attention mediated learning (JAML) intervention	RCT (vs. community treatment control group)	11/1–2 yrs.	Increase in RJA; No change in IJA

(*continued*)

TABLE 4.1 (*Continued*)

Study	Intervention	Design	Participants in experimental treatment group (number/age)	JA outcomes
Stickles Goods, Ishijima, Chang, and Kasari (2013)	JASP/ER: joint attention symbolic play engagement and regulation intervention	RCT (vs. community intensive Applied Behavior Analysis treatment control)	7/3–5 yrs.	No change in IJA
Taylor and Hoch (2008)	Behavioral: prompting, reinforcement	MBL by participants	3/3–8 yrs.	Increase in IJA and RJA
Tsao and Odom (2006)	Sibling mediated: stay, play, talk	MBL by participants	4/3–6 yrs.	Increase in CJA
Vismara and Lyons (2007)	Parent training, Pivotal response training; follow child's lead	Reversal; MBL by participants and behaviors	3/2–3 yrs.	Increase in IJA
Vismara and Rogers (2008)	Early Start Denver Model (ESDM: Rogers & Dawson, 2007)	Case study	1/1 yr.	Increase in IJA
Whalen and Schreibman (2003)	Pivotal response training; discrete trial	MBL by participants	5/4 yrs.	Increase in RJA; Mixed results for IJA
Zercher et al. (2001)	Peer-supported play, modeling	MBL by participants	2/6 yrs.	Increase in RJA; Mixed results for IJA
Large studies (15 or more participants in experimental treatment group)				
Green et al. (2010)	Preschool Autism Communication Trial (PACT)	RCT (vs. community treatment as usual)	77/2–4 yrs.	Increase in CJA
Gulsrud, Kasari, Freeman, and Paparella (2007)	Targeted joint attention intervention (based on Kasari et al., 2006)	RCT (vs. Symbolic Play Intervention control)	17/2–4 yrs.	Increase in CJA
Kaale, Smith, and Sponheim (2012)	Targeted joint attention intervention, based on Kasari et al. (2006)	RCT (vs. community preschool program control)	34/2–5 yrs.	Increase in IJA
Kasari, Freeman, and Paparella (2006)	Targeted joint attention intervention	RCT (vs. symbolic play intervention vs. control in existing early intervention program)	20/3–4 yrs.	Increase in IJA, CJA, and RJA
Kasari, Paparella, Freeman, and Jahromi (2008)	JASP/ER: joint attention symbolic play engagement and regulation intervention (6- and 12-month follow-up to sample in Kasari et al., 2006)	RCT (vs. symbolic play intervention vs. control in existing early intervention program)	20/3–4 yrs.	Increase in IJA and CJA
Kasari, Gulsrud, Wong, Kwon, and Locke (2010)	Focused joint attention intervention; parent training (based on Kasari et al., 2006)	RCT (vs. waitlist control)	19/2–3 yrs.	Increase in RJA; No change in IJA
Landa, Holman, O'Neill, and Stuart (2011)	Interpersonal synchrony intervention	RCT (vs. noninterpersonal synchrony intervention)	24/1–2 yrs.	No change in IJA in either intervention
Wong, Kasari, Freeman, and Paparella (2007)	Behavioral (prompting, social/natural reinforcement, imitation) joint attention intervention	RCT (vs. symbolic play intervention in existing early intervention program)	20/3–4 yrs.	Increase in IJA
Yoder and Stone (2006)	Responsive education and prelinguistic milieu teaching (RPMT)	RCT (vs. PECS: picture exchange communication system, Bondy & Frost, 1994, control)	16/1–3 yrs.	Increase in IJA in both treatments; children with >10 IJA acts at pretest had greater gains from RPMT; children showing < 2 IJA acts at pretest had greater gains from PECS

[1]IJA = initiating joint attention. RJA = responding to joint attention. CJA = coordinated joint attention. RCT = randomized controlled trial. MBL = multiple baseline design. Studies were included in this table if (1) a behavioral treatment, with or without a specific focus on joint attention, was employed with children with autism, autism spectrum disorder, or pervasive developmental disorder–not otherwise specified, and (2) either RJA, IJA, or CJA was assessed before and after the employed treatment. Typical measurement for RJA and IJA included various paradigms, such as gaze-following tasks, individual IJA, or RJA scores from the Autism Diagnostic Observation Schedule (Lord, Rutter, Dilavore, & Risi, 1999), or the Early Social Communication Scales (ESCS: Mundy, Hogan, & Doehring, 1996), among others. CJA was typically measured as a proportion of time children were engaged in focused, cooperative, free play with an adult or peer, wherein gaze alternating and eye contact occurred.

benefits on language as well as cognitive and social development (Jones, Carr, & Feely, 2006; Kasari et al., 2007; Rudd, Cain, & Saxon, 2008; Whalen, Schreibman, & Ingersoll, 2006). At this point, the bulk of large-scale trial evidence (see Table 4.1), for the malleability of joint attention in young children with ASD, originates from the JASP/ER (Kasari et al., 2006), intervention at UCLA which focuses on joint attention as a primary intervention target and outcome. One other large-scale intervention (Green et al., 2010) focusing on communication, more generally, reported increases in bouts of coordinated joint attention between children with ASD and caregivers. Thus, it will be important for future ASD intervention studies to also report specific pre-test and post-test measurements of joint attention. This type of data will enable researchers to determine whether joint attention improvements must be specifically targeted by intervention, or whether joint attention can improve as a function of general positive treatment response to nonspecific interventions. Further, understanding the effects of intervention on joint attention will likely elucidate the mechanisms of healthy social development (Cicchetti & Toth, 2009). Joint attention also appears to mediate responsiveness to early intervention among children with autism (Bono et al., 2004; Yoder & Stone, 2006).

Second, the PDPM proposes that joint attention serves as a foundation for social-cognitive development. Social-cognitive development is defined in terms of advances in the processing of information about self and other, rather than singularly in terms of changes in knowledge about intentionality. Following connectionist cognitive theory (McClelland & Rogers, 2003; Otten, Henson, & Rugg, 2001), the PDPM assumes that information encoded during learning is stored as a distributed neural network activation pattern that involves parallel activation of networks of related semantic information. Additionally, whenever information is acquired during social learning and joint attention, it is also encoded in parallel with the activation of a frontal-temporal-parietal neural network that maps relations between representations of information about self-directed attention and information about the attention of other people. Thus, every time we process information in social learning, we encode it as an activation pattern in a distributed semantic network *in conjunction with* an activation pattern of the anterior-posterior cortical joint attention network (Figure 4.4, Figure 4.5). Recall that deeper information processing and learning occurs best in the context of the simultaneous activation of multiple neural networks during encoding (Otten et al., 2001). If so, joint attention may lead to deeper processing because it adds activation of the distributed social attention network (a form of episodic encoding) to the network activation associated more directly with semantic information. This conjecture provides one interpretation of the observation that joint attention facilitates depth of processing in 9-month-olds (Striano, Chen, Cleveland, & Bradshaw, 2006; Striano, Reid, & Hoel, 2006). It also suggests that part of the learning disability of ASD occurs because children with this disorder do not reap the full benefits of encoding semantic information in conjunction with episodic memory encoded within the integrated processing of self- and other-attention (Mundy et al., 2010).

Some evidence has recently been provided by a sequence of studies of the effects of joint attention on the recognition memory of adults and older children. A recent study has used a virtual reality paradigm to study the effects of picture recognition in college students (Kim & Mundy, 2012). In this study, participants studied pictures of faces, houses, or abstract designs under one of two conditions: (1) the avatar followed the gaze of participants to target pictures on study trials (IJA condition); or (2) participants followed the gaze of an avatar to target pictures on study trials (RJA condition; Figure 4.11). The results of the study indicated that adults correctly recognized significantly more pictures in the IJA than the RJA condition. There are several possible reasons for IJA-related information processing superiority. One is that self-initiated target choice is coupled with better or easier processing than directed target choice. Another possibility is that having another person or avatar follow one's gaze to an object, and the experience of directing or controlling another person's gaze, changes the perception and processing of the common focus of attention (Bayliss, Paul, Cannon, & Tipper, 2006; Mundy & Jarrold, 2010). More interesting, for the topic at hand, the paradigm used by Kim and Mundy (2012) was recently presented to 30 children with higher functioning children with ASD and 50 age-, gender-, and IQ-matched typically developing children (Kim et al., in preparation). The results indicated that the typically developing children displayed an advantage of picture recognition memory in the IJA condition versus the RJA condition, which was comparable to the pattern of data Kim & Mundy (2012) reported for adults. Moreover, the typically developing sample displayed significantly better performance in the IJA condition than the RJA condition, but the ASD sample did not display any differences in recognition memory across the IJA and RJA conditions. These data are consistent with the notion that, in childhood, joint attention does not affect information processing in children with ASD in a manner that is comparable to effects observed for children without ASD.

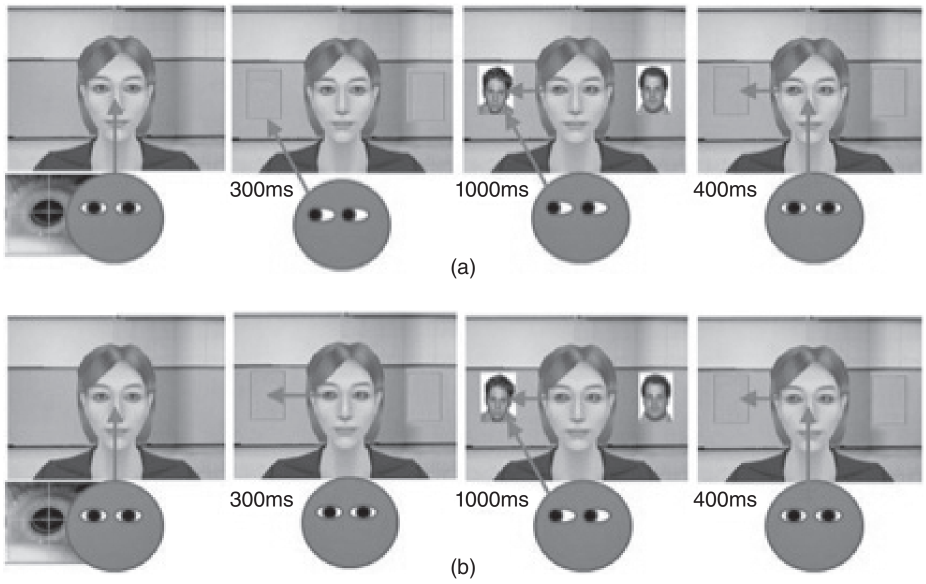

Figure 4.11 Illustration of the IJA and RJA conditions in the Kim & Mundy (2012) joint attention and memory paradigm. In the IJA condition (panel A), the participant first views the avatar, then chooses to shift attention to a stimulus window to the left or right of the avatar. Eye-tracking data then flows to a WorldViz© software program to trigger gaze following in the Avatar and onset of the study picture. The final illustration in panel A indicates that, after a study trial ended, the participant returned to midline, but the Avatar remained fixated on the target area to insure that the participant recognized that the avatar had followed his or her gaze. In the RJA condition, the participant fixated the Avatar and followed the direction of gaze of the avatar to choose a picture to study. Eye tracking control of stimulus onset ensured the picture did not appear until the participant followed the Avatar's gaze. This equated the study time that was available on each trial across IJA and RJA conditions. The Avatar again returned to midline gaze after the participant returned to midline. See footnote 1. *Source:* Reprinted with permission from Kim and Mundy (2012).

A third argument of the PDPM is that overt joint attention becomes increasingly internalized as a social-executive function that supports the social coordination of covert mental attention to cognitive representations. The spontaneous coordination of mental attention and cognitive representations is an essential element of symbolic thought (Tomasello et al., 2005). The PDPM assumes that months of practice of the social coordination of overt attention (i.e., joint attention) in the first years of life is required before this function can be internalized and transformed to an executive facility for socially coordinated covert mental attention and symbolic thought. Thus, symbolic thought processes incorporate, but do not replace, activation of the self-other joint attention system. Joint attention, on the other hand, does not necessarily involve symbolic processes (Mundy et al., 1987). These assumptions of the PDPM are consistent with two recent observations. Joint attention is a unique predictor of pretend play development in children with ASD relative to measures of imitation or executive functions (Rutherford et al., 2007). Moreover, successful symbolic play intervention, which according to the PDPM must involve effects on joint attention, *is* associated with parallel collateral improvements in joint attention in autism. However, intervention with joint attention has less immediate impact on symbolic play behavior (Kasari et al., 2006).

Fourth, the joint processing of attention information also plays a fundamental role in social cognition, defined in terms of the development of knowledge about intentions in self and other (Mundy & Newell, 2007). The assumption here is that when infants or primates practice monitoring others' attention (RJA), statistical learning ultimately leads to the associative rule: *where others' eyes go, their behavior follows* (Jellema, Baker, Wicker, & Perrett, 2000). Similarly, anterior monitoring, or self-awareness of control of visual attention, likely leads to awareness of the self-referenced associative rule: *where my eyes go, my intended behavior follows* (Mundy & Newell, 2007). An integration of the development of these concepts leads to the logical cognitive output: *where others eyes go → their intended behavior follows*, which is a building block of social-cognitive development (Mundy & Newell, 2007). Social cognition of this kind is thought to enable new and more efficient levels of social or cultural learning, and is atypical in ASD.

Finally, the constructivist assumptions of the PDPM stress that motivation factors are part of a crucial fifth path of association between joint attention and social learning. Initiating joint attention requires "choosing" between behavior goals, such as fixated looking at an event, or alternating looking to the event and another person. Choosing among behavior goals is thought to involve frontal and medial cortical processing of the relative reward associated with different goals (Frank & Claus, 2006; Holroyd & Coles, 2002). Therefore, IJA impairment in ASD may be expected to be related to deficits in biobehavioral processes associated with reward sensitivity and motivation (Dawson, 2008; Kasari et al., 1990; Mundy, 1995). Such a deficit, however, could take several forms.

Social stimuli could be aversive in some way for children with ASD. However, the aversion hypothesis is complicated by observations of behaviors indicative of relatively intact caregiver-attachment in many children with ASD and a willingness to engage in playful physical interactions with strangers (e.g., Mundy et al., 1986; Sigman & Ungerer, 1984). On the other hand, social stimuli may not be aversive. Rather, social stimuli may simply not be sufficiently positive to compel social-orienting and joint attention early in the life of children with ASD (Dawson et al., 1998, 2012; Mundy, 1995). Finally, social stimuli could have a positive valence for children with ASD, but be overshadowed by an atypically strong visual preference that make objects, rather than social elements of the world, more interesting (Karmel, Gardner, Swensen, Lennon, & London, 2008; McCleary, Allman, Carver, & Dobkins, 2007; Mundy & Crowson, 1997).

The construction of effective empirical approaches to address these alternatives is one of the outstanding challenges in the science of ASD (Dawson, 2008; Koegel et al., 2003). Research on joint attention, in relation to motivation and the perceived valence of objects in adults (Bayliss et al., 2006), offers one potential route for developmental and functional neurocognitive studies on this topic. For now, though, the literature on intervention in ASD may be the best source of information in this regard. Early intervention studies offer some of the most systematic investigations to date of how to structure social engagements with young children with ASD to modify and increase their motivation to initiate episodes of shared attention and shared experience with others (e.g., Kasari et al., 2006, 2007). The impact of these interventions on the social development of children, their relationships to other people and the world, and transactional effects on their brain development and pathways to resilience (Cicchetti & Toth, 2009), cannot be underestimated.

SUMMARY

Only in its most expansive or grandiose interpretation can the PDPM be viewed as an explanatory model of joint attention, or ASD. Nevertheless, the PDPM does serve a purpose. It presents a new perspective on joint attention that suggests its impairment in ASD is more than an epiphenomenon associated with other fundamental precursor or successor processes. Rather, an impairment in joint attention constitutes a cardinal disruption in the process of healthy social development (Cicchetti & Toth, 2009), that then goes on to further affect social-behavioral development and neural development. This alternative perspective can be summed up in terms of several general principles.

First, ASD is as much about impairments in self-generated activity, as it is about problems in perceiving or responding to the behavior of others. Hence, we need to consider the neurodevelopmental processes and networks involved in initiating behavior and attention control, as well as those involved in perceiving and responding to the behaviors of others, to understand this disorder (Mundy, 2003). Second, joint attention and social cognition are forms of information processing that give rise to knowledge, but their development may not be wholly defined in terms of stages of knowledge acquisition. Third, joint attention is a form of parallel processing because it involves the conjoint perception and analysis of information about self-attention and the attention of other people. This conjoint analysis of information also involves distributed processing across an anterior cortical system for guidance and self-monitoring of internal information about goal-directed attention, and a posterior cortical system for processing external information about the attention-related behavior of other people.

The third principle of the PDPM encourages a multidisciplinary approach to better link constructivist, connectionist neuroscience with parallel and distributed processing impairments in future research on ASD. Exemplary multidisciplinary efforts of this kind have already been published (e.g. Cohen, 2007; Lewis & Elman, 2008). However, the PDPM suggests that such efforts may be better informed with the appreciation of the following hypotheses. A disturbance of a distributed cortical system specifically involved in self-other representational mapping may be at the heart of human social cognition (Decety & Sommerville, 2003), and joint attention may be at the heart of the development of this quintessential form of human cognition, as well as its impairments in ASD.

This leads to the fourth principle of the PDPM. Joint attention is a social executive process that supports all forms of cognition that involve coordinating attention and knowledge about self and others, such as symbolic thought. Thus, neural network activation associated with joint attention is an enduring substrate that plays a role in the unique characteristics of human cognition throughout the life span (Mundy & Newell, 2007). Indeed, it may be one example of the type of hot executive function that Zelazo, Qu, and Muller (2005) theorized are central to social cognition. Hot executive functions are those that entail motivation processes and affect regulation specific to the support of successful goal-directed behavior in social engagement. Following from this notion, the fifth and final principle of the PDPM is that individual differences in the operation of the social executive function of joint attention may be an expression of variance in motivation processes.

FUTURE DIRECTIONS

One of the strengths of the PDPM in application to ASD research is that of hypothesis generation. The model proposes that joint attention is a fundamental, early-developing skill that supports the development of language, social connectedness, social cognition and learning, and social-emotional regulation. This skill is supported by a distributed neural network that integrates information about self (anterior) and other (posterior), and progresses from a learning phase into a routine phase via experience–expectant processes. The first question that follows from this model involves neural plasticity and the development of joint attention. Specifically, studies are needed that assess the development of joint attention and the concurrent development of the PDPM neural network, in typically developing samples, and in ASD samples undergoing interventions. A disruption in joint attention development may have a cardinal role in the endurance of social challenges across the lifespan in ASD, even as other challenges remit. This endurance may be due to the disturbance in the cycle of healthy social development, wherein shared attention and connectedness with others serves as crucial experience that propels brain development, activity, and structure, which then further constrains social abilities and stimulation over time. In light of this idea, prevention trials (Cicchetti & Toth, 2009), which assess whether neurophysiological domains are affected by treatments, are urgently needed. It will also be important to assess multiple levels of effect, such as neurophysiology, genetics, social behavior, and relationships with others, as all of these feed into the stimulation available to a developing organism. Recent work (e.g., Bolte et al., 2006; Faja et al., 2012; Vaughan Van Hecke et al., 2013) established that neural plasticity in response to intervention is possible in ASD and that white matter integrity is linked to early onset and duration of intervention (Pardini et al., 2012). One study reported increases in parietal-temporal EEG activity, perhaps reflective of the posterior network of the PDPM, in toddlers with ASD undergoing early, intensive intervention (Dawson et al., 2012). Thus, it will be critical, for our understanding of the syndrome, that we establish whether the PDPM is responsive to intervention for ASD, and whether there are critical periods that bind this possibility. Additionally, it will be the task of similar studies to determine whether epigenetic effects of amelioration of joint attention deficits occur in response to interventions for ASD. Lastly, studies are needed that describe and measure joint attention across the life span. Although joint attention is well characterized in infancy and early childhood, very little is known about the progression of this uniquely human capability across the latter half of the life span. Studies that assess joint attention and PDPM neural function in adulthood and aging will be informative in this regard. In sum, understanding the nature of these processes, such as the degree to which they are mediated by learning processes or endogenous neural mechanisms, is a vital goal for future multidisciplinary developmental research on social cognition and ASD.

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