Aina Puce · Bennett I. Bertenthal
Editors

The Many Faces of Social Attention

Behavioral and Neural Measures

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Contents

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Chapter 1
New Frontiers of Investigation in Social Attention

Aina Puce and Bennett I. Bertenthal

1.1 Social Attention as a Changing Field of Research

Research into human behavior and its neural bases in general has changed greatly over the past 50 years or so. The earliest studies focused on characterizing behavioral phenomena and teasing apart their behavioral components, in addition to characterizing the timing of neural activity and identifying active brain regions associated with these behavioral observations. More recent studies are beginning to take the pieces of this jigsaw puzzle that were generated from the earlier work to try and put together a picture of embodied cognition that is integrated with activity in multiple brain networks. This latter approach has also changed the way in which laboratory studies are being designed and conducted. The field of social attention has mirrored these changes and in this volume we explore some of the most fascinating new research and also look at unanswered questions—questions that will set the direction for the next decade or so of work in this area.

1.1.1 Initial Studies of Social Attention

Social attention is an intriguing concept—the term is used very frequently in the literature, but rarely does one see it formally defined. The term *social attention* was originally used almost half a century ago (Emery, 2000) to describe the exchange of glances and bodily proximity that distinguish cohesive subgroups of hamadryas baboons, which typically consist of a male and several females, from other individuals

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in the troop (Chance, 1967). The dominant (male) animal is always the focus of attention of subordinate (female) individuals in the group—resulting in a grouping that "underlies or plays a part in all the social relationships by which an animal relates itself to others in a group" (Emery, 2000).

From these original studies of nonhuman primates, the term *social attention* was originally coined to convey the idea of an "attention structure" (appropriate for both human and nonhuman primates) that considers social awareness, as signaled by physical proximity, head and body orientation to conspecifics, as well as dynamic gaze. What was original and novel about the concept of social attention at that time was that attention was being proposed to be a *central part of social organization* (Chance & Larsen, 1976). In those early days of social attention research, many comparative behavioral studies of different nonhuman primates were completed, mainly in the wild, ranging from the savannah environments inhabited by Old World monkeys to the tropical rainforests of the New World. These studies in naturalistic environments indicated that social attention was an important element for any social primate society. In addition, behavioral studies in the laboratory on healthy human infants, children, and adults were also beginning to be performed in group situations or in isolated contexts (Chance & Larsen, 1976).

It is now generally conceded that social attention in humans begins at birth, although there continues to be a lively debate concerning whether this attention occurs due to specialized or more domain-general mechanisms (Nelson, 2001). Regardless, human infants' social attention to bodies, faces, and eyes develops rapidly during the first year and facilitates their understanding and responses to social behaviors from very early on. By 3–4 months of age, infants develop the ability to follow the direction of gaze or pointing gestures, and this experience eventually contributes to their sharing with others visual attention to various aspects of their environment, a process known as *joint attention* (Corkum & Moore, 1995; Scaife & Bruner, 1975; Tomasello, 1995). In the second year of life, these abilities become more extended and more elaborate, forming a scaffold for the development of language skills and theory of mind (Bakeman & Adamson, 1984; Dunham & Dunham, 1995; Ninio & Bruner, 1978; Tomasello, 1995).

1.1.2 Some Definitions

Throughout this volume a number of terms will be used, which we attempt to define broadly here. The use of the term *social attention* in this volume is taken to refer to where, or what, in the (visual) environment an individual has directed their attention to. We make inferences about where another's social attentional focus lies from where they point with their fingers, but most often they will "point with their eyes", (Hadjikhani, Hoge, Snyder, & de Gelder, 2008; Shepherd, 2010) i.e., shift their gaze to their desired focus of visuospatial attention. Head and body position can also be powerful signals as to where social attention is being directed to (Emery, 2000; Langton, Watt, & Bruce, 2000; Perrett, Hietanen, Oram, & Benson, 1992), and these latter cues are at their most useful when others are at a distance to us, where the direction of gaze in the face might not be seen so clear. Altered social attention is commonly signaled by changes in gaze. An observed *averted gaze* serves to redirect attention *away* from the observed individual and *toward* the new locus of their attention in visual space (Klein, Shepherd, & Platt, 2009).

Another's social attention falling on us, as in a *direct gaze*, can be arousing, particularly if it is sustained. In human subjects, changes in skin conductance response and heart rate variability correlating with increased arousal in response to experiencing direct gaze have been described (Helminen, Kaasinen, & Hietanen, 2011; Ponkanen & Hietanen, 2012). These changes in arousal can be influenced by endogenous factors such as state of anxiety (Wieser, Pauli, Alpers, & Muhlberger, 2009) or by exogenous factors such as one's cultural milieu (Akechi et al., 2013). The abundance of terms in the English language to describe gaze indicates that it is considered to be more than just an incoming visual signal. It is notable that we use verbs that evoke perception in sensory modalities other than vision, or we use verbs to describe actions that accompany the word "gaze." For example, we can "hold" the gaze of others, we "feel" another's gaze upon us, we regularly "follow" or "meet" the gaze of another, and indeed another's gaze can be seen as being "penetrating." If we meet the gaze of another, we engage in a *mutual gaz*e exchange (Kleinke, 1986), where we each have become the object of one another's social attention.

Observed gaze aversions in others are thought to trigger a reflexive shift in the observer's visuospatial attention, where the observer's gaze is altered to fall on the same referent in the environment (Friesen & Kingstone, 1998; Itier & Batty, 2009). This induced gaze shift is known as *gaze following* (Butterworth & Cochran, 1980; Corkum & Moore, 1995; Rosati & Hare, 2009). Observed gaze shifts in others can also be regarded as spatial cueing signals, as are arrow cues. Even though both types of stimuli can prime orienting responses in spatial cueing experiments (based on the paradigm developed by Posner (1980)), the social cue represented by the eyes is much more likely to be selected by healthy subjects in the natural environment (Birmingham & Kingstone, 2009).

Gaze following is the cornerstone of joint attention (Itier & Batty, 2009). *Joint attention* is said to occur when two (or more) individuals attend to a common aspect of their (visual) environment during an interaction (Tomasello, 1995). This common focus of attention can be initiated by a change in gaze direction, head orientation, pointing gestures, or verbal cues from one individual that provide the signal to where in the environment the other needs to direct their gaze (or social attention). Joint attention "is not just a geometric phenomenon concerning two lines of visual orientation," but requires that both participants *know and monitor* each other's visuospatial attention to the common aspect of the environment (Tomasello, 1995). For example, typically the individual who initiates the signal for another to gaze to a feature, or person, in the environment will usually follow-up the initial signal with a gaze back to the other person to confirm that their (social) attention has actually been redirected to the desired focus in the environment.

Just because an individual chooses to change their gaze to focus on a particular location in their environment, this may not necessarily be an overt signal to initiate social or joint attention with another. If two observers happen to be looking at the same common point in the environment in the absence of a social interaction or context (see Lachat, Hugueville, Lemarechal, Conty, & George, 2012), this is not considered to be joint attention. Similarly, a daydreamer who is engaged more by their inner mental life than their external surroundings will also show changes in eye position that are driven by their introspections and not by fixations to features in the surrounding visual environment (Schooler et al., 2011). More importantly, someone wanting to deceive another might actually gaze away from their actual point of interest (e.g., Klein et al. (2009)). Hence, one's direction of gaze is not necessarily always an accurate signal of another's apparent social attention. In this sense, social attention always has to be evaluated in terms of some (environmental) context.

As discussed above, when one gazes directly at an individual during a social interaction, then it is said that their *social attention* is directed at the individual being gazed at, because the individual being gazed is a likely *target for a current or future behavior*, in addition to being the likely current focus of their directed visual attention. Direct gaze is a very salient social stimulus, as it can signal a number of different socially relevant cues. It is of particular interest, if it occurs after an explicit visual cue in the form of a gaze aversion that serves as a pointing gesture. In contrast, an averted gaze may signal social rejection, or wanting to avoid social contact or engagement. In addition, a sudden gaze change, away from the observer, could be a potential signal of danger or threat (Hadjikhani et al., 2008; Haxby, Hoffman, & Gobbini, 2002).

Gaze signals are important visual cues not only in humans but also in animal and primate societies (Emery, 2000; Klein et al., 2009; Kleinke, 1986), as they can facilitate social learning (Gariepy et al., 2014) as well as being powerful modifiers of behavior (Bethell, Holmes, Maclarnon, & Semple, 2012; Brumm, Kipper, Riechelmann, & Todt, 2005). For example, chimpanzees have been observed to engage in certain risky behaviors only when they are aware that the gaze of dominant conspecific is occluded (Tomasello, Call, & Hare, 2003). Apes and macaques have even been described to hide their facial expressions behind their hands when they are in the line of sight of other conspecifics (Tanner & Byrne, 1993; Thunstrom, Kuchenbuch, & Young, 2014; de Waal, 1986). Overall, as already noted earlier, while direction of gaze can signal a change in another's social attention, both the social and nonsocial contexts in which the gaze change occurs must be taken into account to successfully interpret the intentions underlying the observed change in gaze.

Most nonhuman primate eyes have relatively small luminance and contrast differences between the iris and sclera; however, in human primates, this visual feature has been amplified by a distinct white sclera and colored iris (Rosati & Hare, 2009). Hence, a change in this high-contrast visual cue (e.g., a gaze aversion) can be well seen even at a distance from the observer (Emery, 2000). Given the importance of the gaze signal for the human primate, much of this volume will deal with social/joint attention as signaled by gaze changes in developing and mature human subjects who have normal or aberrant social cognition. However, we also need to consider the role of objects and goal-directed behaviors in episodes of joint attention—with this synthesis being examined in a few of the chapters of this volume. We also acknowledge that social attention includes much more than the themes examined in our volume. For example, research in nonhuman primates clearly shows that social attentional phenomena (in terms of behavior and neural correlates) show parallels to human subjects, and are crucial for understanding social hierarchy (Chance & Larsen, 1976; Emery, 2000; Gariepy et al., 2014; Klein et al., 2009; Kleinke, 1986).

How has the field of social attention changed since it first developed almost 50 years ago? Initial laboratory-based investigations in human subjects focused on behavior recorded by movie camera, and then later added eye tracking. However, initial studies of eye tracking were performed not to evaluate social attention, but to investigate other viewing phenomena. As early as the 1950s, Yarbus (1967) had been experimenting with reflected light beams to record sequences of fixations when observers were viewing pictures, and this work along with that of Buswell from 1935 established a foundation for studying how the eyes move to, and settle on, different features in a visual scene (Buswell, 1935; Land & Tatler, 2009). The very elaborate laboratory setup established by Yarbus for recording eye movements was, however, difficult to implement in nonexpert hands. In the 1970s, eye-tracking research began to expand rapidly as developments in technology made it possible to simplify the laboratory recording setup, and this was especially true for research on reading (Rayner, 1998).

Although some theorists were inclined to claim that eye tracking and overt attention were a "window into the mind," (e.g., Just & Carpenter, 1980), this view was difficult to reconcile with new findings on covert attention revealing that attention is not always directed toward where the eyes are looking (Posner, 1980). Beginning in the 1990s, eye tracking began to be used in research related to faces and social cognition (Vecera & Johnson, 1995). More recent research and the development of new techniques, such as gaze-contingent eye tracking (Duchowski, 2002), have enabled researchers to resolve a number of methodological challenges and begin to address new questions relating to cognitive and social processes. Today eye tracking is becoming as common as other behavioral measures when studying processes such as social attention and social cognition in infants and adults (e.g., Gredeback, Johnson, & von Hofsten, 2010; Torralba, Oliva, Castelhano, & Henderson, 2006; Vo, Smith, Mital, & Henderson, 2012). Importantly, eye tracking can yield insights not only into where the subject is looking, but also their pupil size can signal their state of autonomic arousal (Steinhauer, Siegle, Condray, & Pless, 2004; Yoss, Moyer, & Hollenhorst, 1970).

Noninvasive electroencephalography (EEG), or the ability to record the spontaneously occurring electrical activity of the brain from the scalp, has been around for many years, with the discovery of the major electrical rhythms of the brain occurring in the earlier part of the twentieth century (Berger & Gloor, 1969; Jasper & Andrews, 1938; Walter, 1936). EEG was initially used mainly for clinical purposes, but as stimulus-elicited changes in the EEG (i.e., event-related potentials or ERPs) were identified with methods such as averaging (Dawson, 1947) EEG began to be used in psychophysiological research. Magnetoencephalography (MEG), a technique that records the changing magnetic fields emitted by the brain, was pioneered in the early 1970s (Cohen, 1972). Functional neuroimaging methods such as positron emission tomography and functional magnetic resonance imaging (fMRI) allowed focal activation in the brain to be visualized for the first time as human subjects performed various activation tasks in the late twentieth century (e.g., Belliveau et al., 1991; Petersen, Fox, Posner, Mintun, & Raichle, 1989). In line with these groundbreaking developments in technology, a brain-behavior line of investigation developed and spawned new disciplines such as cognitive neuroscience (Churchland & Sejnowski, 1988) and social neuroscience (Cacioppo, 1994; Cacioppo, Berntson, Sheridan, & McClintock, 2000). Not surprisingly, EEG/MEG approaches to assessing the brain bases of social attention were implemented more frequently (Mundy, Card, & Fox, 2000; Puce, Smith, & Allison, 2000), as were studies (George, Driver, & Dolan, 2001; Puce, Allison, Bentin, Gore, & McCarthy, 1998). EEG/MEG methods are particularly attractive in that they can provide neural measures of perception/cognition (and social attention) in preverbal humans (Hoehl & Striano, 2010; Hoehl, Reid, Parise, Handl, Palumbo, & Striano, 2009; Mundy et al., 2000).

Overall, there have been many dramatic changes to the practice of science over the last 50 years, which have greatly impacted research into social attention. Next we examine a number of major scientific themes that are relevant to the field of social attention today, and which are covered in the chapters of this volume.

1.1.3 Emerging Themes

Social attention is important in its own right, because it is one of the key pillars in the study of social cognition and theory of mind. In the late twentieth century, the study of social attention became an established area in cognitive and social neuroscience and continued to be an important focal point for research identifying the component brain *regions* that are necessary when evaluating another's social attention (i.e., from a localizationalist perspective). Areas of brain, such as the superior temporal sulcus, amygdala, and orbitofrontal cortex, were repeatedly shown to be particularly sensitive to social attention, as signaled by eye gaze, in both human and nonhuman primates (Baron-Cohen, 1995; Brothers, 1997). Knowing what brain regions are active in social attention, however, could not answer questions regarding the neural mechanisms underlying social attention. To this end in the twenty-first century, neuroimaging research has shifted its focus toward examining the behavior of active brain *networks* that underlie the deployment of social attention, as well as other social, affective, and cognitive processes (Sporns, Chialvo, Kaiser, & Hilgetag, 2004; Sporns, Tononi, & Kotter, 2005). This network-type approach is currently a strong driving force in cognitive and social neuroscience, where the functional and effective connectivity between component brain regions making up a network is beginning to be routinely investigated. Importantly, dynamic temporal functional connectivity across networks is also becoming an important area of study. Preliminary evidence indicates that different networks make transient connections with one another during the course of performing a task, or even during quiet rest (Breakspear, 2004; Zalesky, Fornito, Cocchi, Gollo, & Breakspear, 2014). These studies of dynamic functional connectivity will continue to be important in the future as they will be able to help provide an understanding of how various structures in active brain circuits interact with one another during the course of executing different tasks and goals (Medaglia, Lynall, & Bassett, 2015). Social attention research will greatly benefit from these new network-based research approaches.

The quest to study the neural correlates/networks of social attention extends from the healthy brain to the brains of individuals who have neuropsychiatric disorders, such as ASD and schizophrenia (Bush & Kennedy, Chap. 7, this volume). Similarly, behavior (including eye tracking) and brain activity (as assessed by neurophysiological and hemodynamic methods) have shown some interesting differences between neurotypical individuals and those affected by ASD and schizophrenia. Some of these studies suggest that neurotypical and non-neurotypical individuals might achieve similar behavioral goals by using quite different brain pathways. Developmental studies have also begun to focus on the neural correlates of these processes. The developing human brain appears to harbor a sensitivity to faces, eyes, hands, as well as to situations where the meaning of a simple social interaction needs to be interpreted (Bertenthal & Boyer, Chap. 2; Reid & Dunn Chap. 3, this volume). A consistent theme throughout the entire 50-year period in the study of social attention has been the attempt to generate a complete behavioral account for the deployment of social attention in an individual, as well as the evaluation of social attention in another. Experimental paradigms are gradually becoming more complex as investigators increasingly attempt to create ecologically valid paradigms so as to mimic the social interactions that might occur in real-life situations (Nasiopoulos, Risko, & Kingstone Chap. 5; Bush & Kennedy Chap. 7, this volume).

Brain Pathways for Social Attention

Alternate brain pathways for the flow of social information, particularly with respect to social attention, exist in the primate brain (Klein et al., 2009). On the one hand, visual information traveling via a subcortical route (e.g., to extrastriate cortex via the pulvinar nucleus and superior colliculus, and amygdala) is processed rapidly and travels to extrastriate cortex, and is typically not amenable to conscious awareness (Garvert, Friston, Dolan, & Garrido, 2014; Morris, Ohman, & Dolan, 1999). On the other hand, social information traveling via a cortical route (via the lateral geniculate nucleus) to striate cortex is available for conscious evaluation and can be processed and manipulated. This information is passed on to other regions engaged in more integrative processes that allow the interpretation of the mental states, such as the goals and intentions of conspecifics. Not surprisingly, the neural network for processing faces and eyes is extensive and includes at least six highly specialized regions responsible for perception of identity, head and gaze direction, and facial expressions (Allison, Puce, & McCarthy, 2000; Haxby & Ida Gobbini, 2008; Haxby, Hoffman, & Gobbini, 2000; Ishai, 2008). All of this visual information is rapidly and automatically processed and contributes to higher-level interpretations of others' social behaviors. The similarity between the structure and function of the human and nonhuman primate social brain provides a model system for more invasively studying the analogs of the neural correlates of human social attention and social cognition (e.g., Materna, Dicke, & Thier, 2008)).

The human "social brain" is proposed to consist of four brain networks (Stanley & Adolphs, 2013) (see also Puce et al., Chap. 4, Fig. 1, this volume) that are selectively engaged to different degrees in various aspects of social interactions. Social attention actively engages two of these networks: the so-called mentalizing network and amygdala network. Within these two networks crucial brain regions such as the superior temporal sulcus, the fusiform gyrus, and amygdala play a key role in evaluating an incoming social stimulus. Social attention stimuli are processed quite rapidly in the brain—typically the main differentiation in neural activity occurs around 170–220 ms post-gaze change (Puce et al., 2000), and activity can persist up to almost a second after a gaze change has been viewed, allowing other subsequent behaviors associated with the gaze change to be put into a social context (Ulloa, Puce, Hugueville, & George, 2014). Interestingly, the brain processes dynamic eye movements differently than dynamic mouth movements, even though neural activity to each movement type shows identical temporal characteristics. The latter appear to engage neural mechanisms that are active in evaluating biological motion, whereas the former engage mechanisms that are sensitive to local low-level changes in visual space (Rossi, Parada, Kolchinsky, & Puce, 2014; Rossi, Parada, Latinus, & Puce, 2015). The way this activity ultimately plays out in relation to gaze changes might also depend on the type of information processing mode that the brain is in—a *default* (nonsocial) mode or a *socially aware* mode (see Puce et al., Chap. 4, this volume). In the former, information is processed automatically and this mode is typically used in implicit processing of social attention stimuli. This mode is likely to be active most of the time in daily life, and in some circumstances the information that is gathered in this mode might not be available to conscious awareness. In the latter, top-down processes relevant to the experienced social situation ensure that the information is processed consciously and appropriately with respect to relevant behavioral goals. Not surprisingly, this mode would be active during social interactions. It is tempting to speculate that these two putative modes of processing social information related to the eyes (default and socially aware modes) might correspond to information flow in respective subcortical and cortical pathways.

Automaticity of the Processing of Social Attention Stimuli

In a number of chapters in this volume, the idea is put forward that eyes/social attention stimuli are processed automatically and that information might not be available to conscious awareness (Bertenthal & Boyer, Chap. 2; Puce et al., Chap. 4; Bush & Kennedy, Chap. 7, this volume). The need to focus on the face and, in particular, the eyes, appears to be a natural bias we have when we examine a complex scene that has both people and objects in it (Nasiopoulos, Risko, & Kingstone, Chap. 5, this volume). On the basis of the neuroimaging literature, it is likely that activity in the amygdala may play a prominent role in the generation of these automatic processes. These automatic processing mechanisms may be lacking in individuals with ASD/

autism as they typically spend less time looking at the eyes in a face, or are less likely to look toward the eye region. This can be seen in adults as well as in adolescents and children—signaled most clearly by differences in the "first fixation" in a social scene in ASD/autism relative to typically developing individuals (Schulz, Jones & Klin Chap. 6; Bush & Kennedy Chap. 7, this volume).

Typical Development of Human Social Attention and Joint Attention

Bertenthal and Boyer in Chap. 2 of this volume examine the development of social attention and joint attention during the first year after birth. The idea that selective attention is a dual process is stressed: Initially, shifts of attention are reflexive and driven by the external cues provided by the environment. Later, as the brain develops, the ability to choose where to direct one's selective attention (and social attention) comes on line, allowing the child to engage in joint attention. According to most theorists (e.g., Carpenter & Call, 2013; Tomasello, 2008), joint attention represents a shared understanding of the intentions of self and other and is crucial for the future learning of actions, the development of language, and the ability to predict the goals and intentions of others. Just as critical, however, is the role of the child's social cognitive development in educating attention, which is why it is necessary to consider the reciprocal development of social attention and social understanding.

Bertenthal and Boyer (Chap. 2, this volume) first examine the ability of healthy infants to respond to social cues signaled by stimuli such as gaze, head orientation, vocalizations, and pointing (with the fingers). Joint attention, as initiated by finger pointing as well as changes in gaze, is a particular focus in this chapter. Recent research indicates that the ability of an infant to follow the direction of a pointed finger precedes the ability to generate a finger point by quite a number of months. The ability of the infant to perceive important social cues leads to the subsequent ability to select and direct their attention toward the actions of others. As discussed by Bertenthal and Boyer (Chap. 2, this volume) as well as Schulz, Jones, and Klin (Chap. 6, this volume), human infants not only perceive, but also prefer stimuli with social adaptive value. This initial preference ensures that infants will devote considerable attention to faces and eyes and through this experience will gradually learn about the social behaviors and putative mental states of others. The task of learning about the social world is often simplified by testing infants' attention to faces and eyes in isolation, but this approach runs the risk of misrepresenting infants' responses in more cluttered and naturalistic environments that are filled with multiple people and objects. Thus, it is important to also study how infants' attention to actions and their goals are processed in more visually cluttered environments that resemble daily life. It is somewhat surprising that only recently have image statistics been gathered of what typical infants in their first year of life observe in daily life. Interestingly, initially their visual input prominently features the faces of several individuals that are most involved in their care (Jayaraman, Fausey, & Smith, 2015), and later in their first year the visual input features their own and others' hands as they begin to interact with objects in their environment and learn about their actions (Jayaraman, Fausey, & Smith, 2013).

The attention to actions introduces another theme of considerable significance in studying how infants learn about others' actions and intentions. Infants learn a great deal about themselves and others from observing the effects of their own actions as well as those of others (Bertenthal & Campos, 1990). The discovery of mirror neurons in the monkey's brain by Rizzolatti, Fadiga, Gallese, and Fogassi (1996) and potentially homologous findings in humans (Decety et al., 1997) stimulated a great deal of new research and debate regarding action understanding and its social significance (see also Hickok, 2009). In recent years, there has been growing interest in studying the relation between action understanding and motor experience, and the results suggest that action understanding is greatly facilitated by the availability of motor representations of the corresponding actions (Woodward & Gerson, 2014). Curiously, this aspect of the literature has rarely made contact with research on the development of social attention even though theories, such as the premotor theory of attention (Rizzolatti, Riggio, & Sheliga, 1994), suggest compelling reasons why action understanding will depend intimately on the observer's attention to the actors' social as well as instrumental behaviors. This missing link in the literature is addressed by Bertenthal and Boyer (Chap. 2, this book), who discuss research on how infants' action understanding is modulated by visual attention.

Joint attention has also been studied in the typically developing brain with EEG/ERP methods (Reid & Dunn, Chap. 3, this volume). Specialized brain activity emerges early in development to faces, eyes, and shared referents during joint attention, i.e., in the form of slow ERP responses that decrease in latency and amplitude with increasing age and development. This research converges with behavioral research to demonstrate that infants are biologically prepared to attend to faces and eyes early on in life. Differences in ERP components, such as N170 and Nc, and the positive slow wave (PSW) as a function of stimulus condition indicate that by 4 months of age infants are processing direct and averted gaze differently. Moreover, these neural processes are modulated by facial expression, suggesting that infants are already sensitive to contextual differences by this age. One of the key advantages of neurophysiological research is that the EEG signal can be broken down into different components in the temporal domain with millisecond accuracy, which thus provides greater precision in elucidating what develops over time. For example, infants' differential responding to direct versus averted gaze is indexed by the latency and amplitude of a negative component corresponding to the N170 ERP in adults, but the modulation of eye gaze via facial expression is indexed by the PSW, suggesting that quite different neural mechanisms contribute to this latter process.

One of the key contributions of the chapter by Reid and Dunn (Chap. 3, this volume) is to show that neural processing of objects is modulated by joint attention. For example, Parise, Reid, Stets, and Striano (2008) tested 5-month-old infants' responses to an object that had been previously introduced with, or without, joint attention between the experimenter and the infant. While infants viewed the object, EEG was recorded, and the mid-latency negative component (Nc) showed a greater negative response if this testing followed the joint attention condition (Parise et al., 2008). Converging evidence from other studies supports these results, which, when taken together, suggest that infants are processing some of the social-communicative information associated with joint attention at a much younger age than is typically reported for joint attention. This result, revealing earlier processing of objects than suggested by behavioral studies, is a common finding with electrophysiological measurements of brain activity, but the challenge is to map these findings onto behavioral and cognitive developments. At least with regard to joint attention to objects, these findings suggest that social attention facilitates the processing of objects and contributes to infants learning about their structural and functional properties. As such, these findings converge with the views of Bertenthal and Boyer (Chap. 2, this volume) that the visual exploration that occurs during joint attention contributes to infants' learning about the social and physical world.

Aberrant Human Social Attention: in Developing and Mature Humans

In a number of neuropsychiatric disorders, such as autism, ASD, and schizophrenia, individuals may experience difficulty in attending to informative social cues or reading the information provided by these cues. Aberrant social attention in the developing brain is discussed by Schulz et al. in Chap. 6 of this volume, whereas that in the more mature brain is dealt with by Bush and Kennedy in Chap. 7 of this volume.

Schulz et al. (Chap. 6, this volume) propose that an early attentional focus on the human face and eyes occurs with the information being processed by subcortical pathways during the first month or two of life. With subsequent development there is a switch from subcortical to cortical pathways, which is accompanied by a transient behavioral decrease in attentional focus on eyes/face in the typically developing individual. In individuals who subsequently develop autism/ASD the switch may well occur at this same time, but it is likely that the cortical pathways are not functioning correctly. Schulz et al. argue that the development of brain pathways is shaped, or "canalized", by incoming sensory experiences. Given that in typical development the focus is on people's faces and eyes, the bias created for this type of visual input sets into play the development of further specialization in the brain as a function of the interactions between the infant's visual experiences and brain maturation. Conversely, in autism/ASD the preference for faces is initially as strong as it is in typically developing infants, but it declines during the first year, whereas this preference increases for typically developing infants. It is hypothesized that these early abnormalities in social attention disrupt infants' formative social experiences with caregivers and others and result in cascading downstream effects that affect typical neural, cognitive, and behavioral development.

In the chapter by Schulz et al., research is also reviewed, which leads to a novel hypothesis as to why children with ASD show greater interest in the synchrony between speech and mouth movements than typically developing children. Rather than suggesting that these infants prefer looking at the mouth relative to the eyes, this research reveals that these children are likely to be biased to attend to audiovisual synchrony *in general*. Audiovisual synchrony is present in movements of the face and associated vocalizations, and thus may explain the focus on the mouth that many individuals with ASD are said to have. The different (nonsocial) focus in ASD therefore sets into motion the development of brain pathways that are appropriate to processing the incoming sensory input, but which are likely to differ relative to those individuals with a neurotypical profile. If this is the case, then the same visual input is likely to be processed by potentially different mechanisms, modes, or even brain pathways in a neurotypical individual relative to one who has ASD. Data from multiple studies indicate that behavior is very different in neurotypical versus ASD adults, adolescents, and children (Bush & Kennedy, Chap. 7, this volume).

Bush and Kennedy (Chap. 7, this volume) make clear that disruptions in social attention among children with ASD persist into adulthood, and these social deficits continue to impact their behavior, cognition, and brain functioning. The deficits associated with ASD fall along a spectrum of social behaviors and there is considerable heterogeneity in this subject population, which makes the assessment of common root causes extremely challenging. Three categories of explanations are considered for these observed differences:

(1) behavioral, cognitive, and neural factors;
(2) altered developmental trajectories;
(3) real-time processing of social behavior modulated by (social) attention.

Currently, it is difficult to reach any consensus on a potentially plausible and correct explanation because of the many inconsistencies and contradictions in the literature. However, Bush and Kennedy focus on aberrant social attention and convincingly demonstrate that these deficits have downstream consequences resulting in neural and behavioral abnormalities that manifest with more complex social processes. One of the important contributions of this chapter is to illustrate why revealing differences between neurotypical and ASD adults often requires extremely sensitive measures across multiple assessment methods, such as those provided by eye tracking and neuroimaging while individuals engage in complex tasks.

In spite of some residual reservations about the utility of eye tracking for studying attention, this measure is ideally suited for investigating social attention because it records not only what observers look at, but also when. As Bush and Kennedy point out, global measures of visual attention may not reveal any differences between neurotypical and ASD adults, because the differences are confined to specific moments or specific features that are only looked at very briefly. The most informative social cues are sometimes the most fleeting and subtle, and therefore it requires very detailed measures of attention that have high temporal resolution to gather this information. A related point is that these subtle cues or more complex situations are typically not reproduced in laboratory experiments, and thus they tend to greatly underestimate the differences between neurotypical and ASD adults.

The deficits in social attention observed in individuals with ASD could be either a function of aberrant processing of the input, or the deficits might be associated with higher-level functions, such as theory of mind—an important function of the social brain. To adjudicate between these interpretations, it is necessary to consider both the behavioral and neural correlates of these processes. As already noted, the mentalizing and amygdala networks in the brain are key components for the successful deployment of social attention. Within these two networks, three core brain regions are considered:

(1) the fusiform face area (FFA);
(2) the amygdala;
(3) the superior temporal sulcus (STS).

Results from existing neuroimaging studies suggest that it is insufficient to simply measure the level of activation in these regions, because this is often a consequence of the level of attention devoted to the social stimulus (e.g., face or eyes). In addition, the *interactions* between these three core brain regions need also to be considered. Clearly, these findings have important implications for therapies related to the treatment of ASD.

Social Attention vs. Social Cognition

One of the most important implications emerging from Chap. 7 by Bush and Kennedy is that it is clearly necessary to distinguish between social attention and social cognition when studying ASD. As we have indicated earlier, social attention is the crucial front-end to all higher-level social processes, including the recognition of emotions and others' mental states (theory of mind). It is obvious that it is necessary for observers to access social information before they can interpret it. Converging evidence suggests that deficits in social attention are at least sometimes the culprit for misunderstanding others' social behaviors, and thus we cannot assume what is the cause and what is the consequence of ASD without independently assessing both social attention and social cognition. Similar conclusions about a reciprocal relation between social attention and social cognition are discussed by Bertenthal and Boyer (Chap. 2, this volume).

Social learning represents an important link between social attention and social cognition. It is repeatedly emphasized in this volume that our social knowledge depends on our social experiences, but the meditational process by which this occurs is often assumed but not directly studied. It should also be noted that processes involving social learning are also extremely important for the normal development of spoken language (Tomasello, 2008).

Social Presence

Nasiopoulos, Risko, & Kingstone in Chap. 5 present the idea of social presence and examine how it affects social attention. *Social presence* is defined as the influence of the physical presence of another on an individual's behavior, when all other influences have been removed. Interestingly, the effects of social presence are task dependent. For simple tasks, such as skilled motor actions, there is a *positive effect* of social presence on behavior. In contrast, for complex tasks that typically require flexible and varied behaviors, *negative effects* of social presence on behavior have been consistently reported. In particular, overt task-related behaviors in individuals can be strongly modulated by social presence if the task in question has a personally significant element for the subject who is performing the task. Personal significance can be driven by avoidance of embarrassment (perhaps because of a lack of skill) or by generating a favorable impression of oneself to others.

A related, but more subtle, effect to social presence is *implied presence*. Here, environments that have a closed-circuit television recording setup, or a one-way window, where the subject knows that others are watching them, can also generate these differences in task-related behaviors. Most typically, the individuals who feel that they are being watched will be more likely to adhere to social norms, or will engage in behaviors that potentially will increase their social desirability. Interestingly, the effects of implied presence can also occur with displays of isolated, disembodied pairs of eyes. The implications of this last point are far reaching and there is at least one case study of advertisers manipulating the direction of eyes appearing on a product to increase sales (Musicus, Tal, & Wansink, 2015).

Does social presence affect gaze? It should be remembered that gaze serves a dual function: the eyes are used both to collect information and to communicate with others. Nasiopoulos, Risko, and Kingstone (Chap. 5, this volume) also examine how looking behavior can be influenced by social presence, by using experimental manipulations where the subject wears an eye tracker while they interact with their environment. They demonstrate some interesting effects on looking behaviors whereby subjects will vary the amount of monitoring they do on their own looking behavior, following a reduction of implied social presence via a habituation-type manipulation. The described studies underscore the importance of integrating social psychological variables in the study of social attention, as unexpected changes in behavior might be observed when running paradigms in the laboratory because of the presence of experimenters.

Using Naturalistic Task/Environments to Evaluate Social Attention (and Social Cognition)

Laboratory-based visual stimuli in social attention experiments have typically consisted of (static) images of isolated faces, and are unnatural/unrealistic and do not have the richness of real-world visual environments (Bertenthal & Boyer, Chap. 2; Puce et al., Chap. 4; Nasiolpoulos et al., Chap. 5; Bush & Kennedy Chap. 7, this volume). When behavior is compared between impoverished laboratory-based stimuli and real-world environments, quite different types of results related to social attention are evidenced by eye-tracking data (Nasiopoulos et al., Chap. 5, this volume). Specifically, when neurotypical research subjects look at stimuli in the laboratory that are presented on a computer screen, such as static images of directly gazing faces, they typically focus on, and scrutinize, the face and the eyes. In contrast, when subjects are walking around in a real-life environment they will typically only scrutinize the faces and the eyes of others when that individual is suitably far away from them—subjects will tend to avoid gazing at the faces and eyes of strangers if they encounter an approaching individual. Therefore, looking behavior in a laboratory experiment risks being very different (and indeed could be completely opposite) to that which occurs in a real-life situation. In particular, it appears that gaze following and also gaze cueing behavior in real life appears also to be very different to that observed in the laboratory with isolated, static computerized stimuli. This is a very concerning issue for the existing literature dealing with social cognition in healthy subjects. Notably, laboratory-based studies of individuals with social attention deficits, such as those with ASD, often do not show deficits, completely in contrast to what those individuals experience in real life. Not only is there a difficulty in orienting to a rapid, fleeting social stimulus in a busy visual environment, but also the focus of interest in a complex scene may well be quite different to that of a neurotypical individual. The studies of Nasiopoulos et al. (Chap. 5, this volume) raise these somewhat controversial, but nevertheless critical, questions.

These above questions not only apply to studies of the mature brain, but also are crucial in studies of development (Bertenthal & Boyer Chap. 2; Schulz et al., Chap. 6; Bush & Kennedy Chap. 7, this volume). In this vein, important refinements in experimental procedures in infant studies, such as gaze-contingent cueing, allow significantly greater numbers of trials to be collected in behavioral and eye-tracking studies (Bertenthal & Boyer, Chap. 2, this volume), and thus provide new opportunities for conducting developmental investigations.

Future Challenges and Issues over the Next Decade in Social Attention Research

As already noted, the development of new technologies and new scientific fields has vastly impacted research into social attention. The change in reductionist philosophy in brain-mapping studies (in the later twentieth century) to a more holistic network-driven approach in the twenty-first century is also likely to change the way experimenters design new experiments and formulate scientific conclusions. Bertenthal and Puce (Chap. 8, this volume) attempt to speculate as to how the field might change in the next decade or so, taking into account the latest developments not only in social attention research, but also in science and technology more generally.

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Chapter 2
The Development of Social Attention in Human Infants

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2.1 Introduction

Humans are social creatures from birth and devote a great deal of time attending to faces, bodies, and actions throughout their lives. Social attention and interpretation of others' eyes, faces, and actions is foundational to how we communicate, learn about the social and physical world, regulate emotions, and develop attachments with others. By adulthood, and most likely long before, we are all *experts* in our social understanding of other people. This understanding includes a number of core principles:

(1) From observing eye gaze, and head and body orientation, we readily detect other's focus of attention (e.g., Butterworth & Jarrett, 1991; Langton, Watt, & Bruce, 2000; Nummenmaa & Calder, 2009).
(2) We reflexively or automatically orient our own attention to the same location resulting in eye contact (direct or mutual gaze) or attention to objects and events (averted gaze) (e.g., Driver et al. 1999; Friesen & Kingston, 1998; Frischen, Bayliss, & Tipper, 2007).
(3) Our attention to observed actions automatically activates corresponding motor programs (Bertenthal & Longo, 2008; Kilner, Marchant, & Frith, 2006; Michael et al., 2014; Rizzolatti & Craighero, 2004).
(4) We infer state of mind (i.e., intentions, desires, beliefs) from these actions by others (e.g., Blakemore & Decety, 2001; Gallese, Rochat, Cossu, &

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Sinigaglia 2009; Wellman, Lopez-Duran, LaBounty & Hamilton, 2008; Woodward, 2009).

This chapter is concerned with the origins and early development of these core principles. Our goal is not to provide a comprehensive review, but rather to make a case for studying social attention as a developmental process and not as a developmental outcome. The contributions of social attention as a process are often lost in contemporary research studies involving social stimuli. In an effort to conduct experimentally rigorous and well-controlled experiments using real-time measures such as eye tracking or electroencephalogram (EEG), many of these studies have reduced the stimulus situations to static faces, or disembodied arms reaching for an object. What are the implications of using these simple stimuli? In essence, these paradigms forgo the process of attentional selection because the stimuli are all preselected. Yet, selective attention is often the key to what we understand, because it represents the ability to maintain a behavioral or cognitive set amidst distracting or competing stimuli.

In more natural social situations, selective attention is essential and involves two interrelated processes (Corbetta & Shulman, 2002):

(1) Exogenous orienting, or stimulus-driven attention, is under the control of the stimulus and is considered to be reflexive and automatic. This process is present from birth and explains why neonates reveal some preferences from birth.
(2) Endogenous orienting, or goal-directed attention, is the intentional allocation of attentional resources to a predetermined location or space. This type of orienting occurs when attention is directed according to an observer's goals or desires, allowing the focus of attention to be manipulated by the demands of the task or situation.

Endogenous orienting depends on higher-level processes that develop with age and experience, and significantly influence what the child decides to look at. *The development of social understanding is thus reciprocally related to the development of social attention, in that the child's understanding of others will influence where the child directs attention, and where attention is directed will contribute to what the child learns about the social behaviors of others.*

In the remainder of this chapter, we will present a selective review of infants' social attention and social understanding in order to show how the two are reciprocally related in the development of joint attention. While the precise definition of this behavior continues to be debated, it involves at a minimum attention to another individual and to the referent of his or her attention (Shepherd & Cappuccio, 2012). We begin with a brief summary of infants' social attention, which will highlight the transition from dyadic (face-to-face interactions in which adults and infants take turns exchanging facial expressions and vocalizations) to triadic social interactions (two individuals looking back and forth at an object and at each other). To better understand these developmental changes, it is necessary to focus on the processes involved. Three processes will be considered:

(1) shared direction of attention between infant and social partner;
(2) contributions of motor experience to action understanding; and
(3) coordination of attention between infant and social partner.

We will conclude by returning to the reciprocal development of social attention and social understanding in order to offer some new insights into how joint attention develops during the infant's first year.

2.2 Development of Social Attention

2.2.1 Face Perception and Gaze Following

Beginning at birth infants attend preferentially to attractive faces, and are most sensitive to the presence of eyes in a face (Batki, Baron-Cohen, Wheelright, Connellan, & Ahluwalia, 2000). In addition, newborn infants prefer to orient to faces displaying direct gaze (Farroni, Csibra, Simion, & Johnson, 2002), and show a rudimentary form of gaze following (Farroni, Massaccesi, Pividori & Johnson, 2004). These newborn behaviors are hypothesized to be based largely (though not exclusively) on a subcortical visuomotor pathway involving the superior colliculus and pulvinar, which is sensitive to movement and low spatial frequency visual information (Johnson, 2005). Some evidence suggests that newborns are also able to recognize their mother's face (e.g., Bushnell, 2001), but, in general, face perception does not begin to show significant development until around 2 months of age, as the cortical regions that mediate face perception in adults start to become functional (Johnson, 2011). Electrophysiological studies of infants viewing upright and inverted faces using event-related potentials (ERPs), source localization, and gamma oscillations reveal that both gaze and face perceptions show significant changes with regard to amplitude and latency of the response as a function of age, and also begin to recruit more frontal areas of the brain (Farroni et al., 2004; Grossman & Johnson, 2007; Grossman et al., 2008; Halit, de Haan, & Johnson, 2003). In addition, these findings suggest that the brain is prepared to extract gaze information from upright faces, which becomes more adept with development, such that mutual gaze is detected independent of head angle; moreover, direct and averted gaze serve different functions (ostensive cue establishing a communicative connection versus directing social partner's attention in a different direction) and recruit different cortical regions (Grossman & Farroni, 2009).

At a behavioral level, face perception develops rapidly after 2 months of age. Beginning around 10 weeks, infants fixate more consistently on the internal features of a face than on the external features and contours (Haith, Bergman, & Moore, 1977; Hunnius & Geuze, 2004). By 3 months, infants begin to differentiate faces based on the social categories of gender and race (Kelly et al., 2005; Quinn, Yahr, Kunn, Slater, & Pascalis, 2002). Infants' preference for faces continues to develop during the first few months, and becomes sufficiently robust by 6 months of age that they reveal a face pop-out effect when presented with faces among an array of items (i.e., infants orient more frequently and longer to a face than to other items in a stimulus array; di Giorgio, Turati, Altoe, & Simion, 2012; Gliga, Elsabbagh, Andravidzou,

& Johnson, 2009). Critically, these results cannot be attributed to low-level featural salience (e.g., color, intensity, contrast, orientation), because faces were rarely the most visually salient item in the array (Elsabbagh et al., 2013; Gluckman & Johnson, 2013).

Beyond 6 months of age, infants' face perception becomes more narrowly tuned. For example, 6-month-old infants discriminate faces not only from their own species but from an unfamiliar species (i.e., nonhuman primates) as well, whereas this is no longer true for 9-month-old infants (e.g., Pascalis, de Haan, & Nelson, 2002). Similar to speech perception, which changes with experience, the evidence suggests that face processing becomes more specific to those faces appearing in one's own environment (Nelson, 2001). Further support for experiential contributions to the narrowing of the face prototype is that infants given repeated experience with monkey faces retain the ability to discriminate these faces at 9 months of age (Pascalis et al., 2005; Scott & Monesson, 2009). A similar phenomenon is observed with infants viewing faces from other races. By 9 months of age, infants' discrimination of faces is restricted to their own racial group (Kelly et al., 2007; 2009).

The mechanisms responsible for such precocious attention and perception of faces have been a source of debate for decades (e.g., Fantz, 1965). Johnson and colleagues (Grossman et al., 2008; Johnson, 2011; Senju & Johnson, 2009) hypothesize that neither the maturation of the brain nor the face-specific experiences of young infants are sufficient to account for developmental changes in face perception and eye gaze processing. Instead, they propose that development is a function of increasing specialization and localization of face-evoked activity in the brain in response to the interaction between maturational changes and specific experiences of the infant. Their model suggests an intrinsic bias to attend to, and track, face-like stimuli from birth, which increases the likelihood that infants will learn about faces during their foraging of environmental input (Johnson, 2011; Johnson, & Morton, 1991; Morton & Johnson, 1991). Other models attribute early face preferences to domain-general relations between features that are highly correlated with the structure of the face (Cassia, Turati, & Simion, 2004; Simion, Valenza, Cassia, Turati, & Umilta, 2002; Turati, Simion, Milani, & Umilta, 2002). Still, other models suggest innate modules that are responsible for eye direction detectors and/or face perception (e.g., Baron-Cohen, 1995). Although we anticipate that the origins of these behaviors will remain controversial for some time to come, our current interest is directed more toward how social attention continues to develop with age, which we believe is most faithfully captured by increasing specialization emerging from the interaction between brain maturation and experience.

2.2.2 Contextual Modulation of Faces and Objects

While face perception and eye gaze processing are necessary precursors for subsequent improvements in infants' responses to eye gaze and other social responses, the development of these processes is not sufficient to account for the complexity of observed behaviors. By 1 month of age infants seek eye contact in social situations, and receiving this contact while nursing potentiates the effect of sucrose delivery on calming a distressed baby (Zeifman, Delaney, & Blass, 1996). Beginning at 9 weeks of age, infants fixate more consistently on an adult's eyes when the adult is speaking rather than when the adult is silent (Haith, Bergman, & Moore, 1977). Three-month-old infants smile in response to eye contact and decrease smiling when a partner's gaze is averted (Hains & Muir, 1996). By 3–4 months infants respond differentially to contingent and noncontingent (or still) faces (Bigelow & Power, 2014; Tronick & Cohn, 1989). Infants are even more distressed at a still face than at separation from the mother (Field, Vega-Lahr, Scafidi, & Goldstein, 1986). Babies get equally upset if the still face is posed by the live mother or a closed-circuit television image, but there is no change in infants' behavior if the virtual mother continues to be expressive while the sound is turned off (Gusella, Muir, & Tronick, 1988). At 4 months, eye contact enhances face recognition (Farroni, Massaccesi, Menon & Johnson, 2007) and engages cortical areas associated with processing communicative signals in adults (Grossman & Farroni, 2009). By 6 months of age, direct gaze functions as a form of ostensive communication and increases the rate of subsequent gaze following (Senju & Csibra, 2008).

Recent ERP data indicate that adults' gaze facilitates object processing in infants as young as 4 months of age (Reid, Striano, Kaufman, & Johnson, 2004). In this study, objects that were previously cued by eye gaze elicited a lower-amplitude positive slow wave between 700 and 1000 ms over the right frontotemporal scalp, suggesting that eye gaze facilitates learning since a diminished positive slow wave is associated with deeper memory encoding (Nelson & Collins, 1991). In a variant of this paradigm (Striano, Kopp, Grossmann, & Reid, 2006), 9-month-old infants interacted with a live adult who either first looked at the infant before looking at an object (joint attention condition) or only looked at the object (no joint attention condition). In contrast to the no joint attention condition, objects presented in the joint attention condition elicited a greater negative component (Nc) peaking at about 500 ms over the frontal–central scalp. Nc is putatively generated in the prefrontal cortex while attending to a visual stimulus (Reynolds & Richards, 2005), suggesting that more attentional resources are devoted to objects that share attention. Although these studies are suggestive of social learning from eye gaze and joint attention (see Reid & Dunn, Chap. 3, this volume) for an expanded discussion of this issue), they lack converging behavioral evidence confirming that the cortical response is functionally significant (for an exception, see Wahl, Michel, Pauen, & Hoehl, 2013).

2.2.3 Dyadic and Triadic Interactions

Beginning around 2–3 months of age, infants are often engaged in dyadic interaction with their caregivers, ensuring that faces are a prominent part of their visual experience. These face-to-face interactions offer infants opportunities for learning about reciprocity and turn-taking, as well as self-efficacy (i.e., their behaviors affect others in a consistent and predictable manner) (Lock & Zukow-Goldring, 2010). By 6 months of age, infants are beginning to lose their interest in face-to-face interactions, and their caregivers begin to direct their attention more toward objects, which they are now able to reach and explore with their hands (Fogel, 2011). As a consequence, they are much more likely to divide their attention between exploring objects with their eyes and hands and interacting with social partners (Lock & Zukow-Goldring, 2010). For the next few months they typically distribute their attention to either objects or social partners, but they still must learn to share their attention about a common referent with someone else. It is not until the latter part of the first year that evidence for triadic abilities, such as joint attention, is reported, suggesting that infants at this age attribute intentional states to social partners (Carpenter, Nagell, & Tomasello, 1998; Tomasello, Carpenter, Call, Behne, & Moll, 2005). Infants begin to establish joint attention with an adult toward an object (Bakeman & Adamson, 1984), use expressed emotions toward an object to guide their own behaviors (i.e., social referencing; Mumme & Fernald, 2003), and even point to an object communicatively (Carpenter et al., 1998).

To avoid any misunderstanding, we wish to distinguish between joint attention and the shared gaze that occurs when two individuals look at the same object. Beginning with the pioneering study of gaze following by Scaife and Bruner (1975), there is now considerable evidence suggesting that infants begin to follow the gaze shifts of another individual as early as 3 months of age (e.g., D'Entremont, Haines, & Muir, 1977; Farroni, Johnson, Brockbank, & Simion, 2000; Hood, Willen, & Driver, 1998). Although this behavior signals some preliminary form of joint visual attention, a number of researchers suggest that simply following someone's gaze is not the same as comprehending that this gaze shift is intended to direct one's attention to something as a means of communicating about it (e.g., Butterworth, 2003; Tomasello, 2008). We concur and believe that it is useful to differentiate between an earlier and later form of joint attention. At the first level, infants need only to selectively orient to some interesting distal referent based on another's social cues, whereas at the second level infants need also to comprehend the mental state of the social partner and relate it to their own mental state. This latter level of comprehension is believed to develop around 9–12 months of age as infants establish triadic forms of communication signaled by looking back and forth between the social partner and distal referent (Carpenter & Call, 2013). In order for infants to participate with others and establish joint goals, it is necessary for them to understand others' intentions.

Laboratory studies testing specifically for an intentional, target-directed understanding of gaze find the earliest evidence at around 8–9 months of age, but only under limited conditions primarily involving a succession of acts performed over multiple equifinal paths (Johnson, Ok, & Luo, 2007). In this study, infants were familiarized to an actor who looked repeatedly, but with variations, toward one of two objects (i.e., referred to as the familiar goal) located to the left or right of the actor. On test trials, the location of the two objects was switched, and infants showed preferential looking to the event depicting the actor looking at the previously unattended object (i.e., referred to as the new goal) as opposed to the previously unattended location. Although this evidence is suggestive, it is not definitive as infants will represent even novel nonhuman actions as goal-directed under these conditions (Biro & Leslie, 2007; Gergely, Bekkering, & Kiraly, 2002). As such, the interpretation of these findings remains somewhat ambiguous because they may be a result of infants attributing intentionality to both animate and inanimate agents, or alternatively, infants were unintentionally trained during these experiments—an interpretive problem common to many developmental studies (Bertenthal, Gredebäck, & Boyer, 2013).

Interestingly, infants do not show preferential looking to the new goal until 12 months of age if the actor turns his or her eyes and head in the direction of the object without subsequently varying the focus of his or her attention (Johnson et al., 2007; Woodward, 2003), and this result is not consistently replicated (Thoermer & Sodian, 2001). Furthermore, it is not entirely clear whether infants are following the direction of eye gaze or the orientation of the head. For example, Brooks and Meltzoff (2002) showed that 9-month-old infants are just as likely to turn their heads when following an adult's head turn regardless of whether the eyes were open or closed. Perhaps, this issue is less of a concern when considering whether infants understand another's intentions, because these intentions could be signaled by eye direction, or head orientation, or both, but nevertheless this last result serves to underscore the fragility of the evidence for joint attention when observing gaze following. In the next section, we will contrast this evidence with point following which appears to avoid some of these problems. One problem common to virtually all laboratory studies, however, is that only one adult actor is typically presented, displaying highly scripted and very salient behaviors; thus, it is difficult to know how well the results from these experiments generalize to more naturalistic situations.

In spite of these various caveats and cautions concerning the interpretation of gaze following, there is considerable evidence suggesting that infants acquire the social–cognitive prerequisites for understanding their own as well as others' intentions by 9–12 months of age. For example, infants begin pointing to objects communicatively (Butterworth, 2003; Carpenter et al., 1998); they become upset when their goals are blocked and are pleased when they achieve an intended goal (Fogel, 2011); they seek appraisal from caregivers to regulate their own emotions (Mumme & Fernald, 2003; Sorce, Emde, Campos, & Klinnert, 1985); and they expect social partners to express interest in shared referents (Liszkowski, Carpenter, & Tomasello, 2007). Converging evidence is provided by imitation studies, where infants by 10–12 months of age observe the unsuccessful attempts of a model to perform a goal-directed action (e.g., pulling apart a toy barbell) and then perform the target act in spite of not seeing it (Brandone & Wellman, 2009; Legerstee & Markova, 2008; Meltzoff, 1995). These results suggest that infants can infer the unseen goals or intentions of the model; otherwise, it would not have been possible for them to perform the intended actions. In view of this evidence, many theorists claim that the social–cognitive prerequisites for joint attention are available by 9–12 months of age and we concur with this conclusion. What remains less clear is how these social–cognitive skills develop. As discussed in the beginning of this chapter, we hypothesize that developmental changes in social attention are reciprocally related to changes in social understanding, and thus infants' continuous and repeated experiences observing and interacting with their caregivers and other social partners tutor their attention as well as their perceptions of others' behaviors.

2.3 Shared Direction of Attention Between Infant and Social Partner

2.3.1 Gaze Following

What social information is used by infants to direct their attention? We have already briefly reviewed evidence suggesting that they are sensitive to gaze direction from birth: they prefer to look at faces displaying direct gaze from birth and they tend to orient in the direction of averted gaze by 3 months of age (Farroni et al., 2002; Hood et al., 1998). Here, we consider in more detail the interpretation of these behaviors, how they change with age, and whether shifts in attention are restricted to following eye gaze.

Extensive research with adults over the past two decades reveals that the eyes direct attention to specific places and objects through gaze (e.g., Frischen et al., 2007; Langton et al., 2000). If someone is looking directly at us, then we are the object of their attention. Direct or mutual gaze is a prerequisite to social interactions and serves as an ostensive cue informing the observer that there is an intent to communicate with them. By contrast, averted gaze directed away from the observer is interpreted as trying to direct one's attention toward somewhere, something, or someone else, and we typically respond by shifting our attention in the direction pointed to by the eyes. Averted gaze is frequently used in spatial cueing paradigms (Posner, 1980) to demonstrate orienting of attention by gaze. When a face is centrally presented prior to the onset of a peripheral target, detection is faster when the target appears on the side cued by the averted gaze (e.g., Friesen & Kingstone, 1998). The finding that this effect is very fast (100 ms) and occurs when gaze direction is not predictive or even counterpredictive of target location has been interpreted as reflecting an automatic, reflexive, and stimulus-driven (exogenous) orienting of attention which is very difficult to inhibit (e.g., Driver et al., 1999; Friesen, Ristic, & Kingstone, 2004; Langton & Bruce, 1999).

2.3.2 Interaction Between Different Social Cues

Currently, it is not clear whether this reflexive orienting is specific to eye gaze or to social stimuli more generally. Humans possess remarkable social attention skills that involve not only eye gaze but also head and body orientation and especially pointing gestures (Langton et al., 2000). Indeed, these gestures may provide a more accurate cue to the spatial location of a referent than either eye or head orientation. Although some researchers suggest that gaze cueing is unique because of the high contrast between a white sclera and a dark iris (e.g., Emery, 2000), there is little empirical evidence to support this claim. In fact, it has been suggested that pointing gestures may provide a more salient and accurate cue to the spatial location of a referent than either eye or head orientation (e.g., Butterworth, 2003; Deák, Walden, Kaiser, & Lewis, 2008; Langton et al., 2000; Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002). Similar to eye gaze, these gestures receive dedicated processing by the superior temporal sulcus region of the brain (Materna, Dicke, & Their, 2008). Moreover, Burton, Bindemann, Langton, Schweinberger, and Jenkins (2009) directly compared the likelihood of an unattended pointing hand, or gaze cue distractor, interfering with the speed of responding to a gaze or pointing hand cue. Critically, the results revealed that the pointing hand distractor interfered with shifting attention to the gaze cue target, but not vice versa. In another study, the orientation of the head was also observed to interfere with perceiving the direction of eye gaze (Langton, 2000). In sum, the most parsimonious interpretation of the data is that all of these deictic cues contribute to how readily we detect others' focus of attention, orient our own attention to the same location, and draw social–cognitive inferences regarding their goals, intentions, and actions (Langton et al., 2000).

What does the evidence reveal about infants' responses to different deictic cues? Most of the previous research confounds gaze cueing with head and body orientation (e.g., D'Entremont et al.,1997; Scaife & Bruner, 1975), and some evidence suggests that infants do not distinguish between gaze cueing and head and body orientation until their second year (Caron, Butler, & Brooks, 2002; Moore & Corkum, 1998). This confound was avoided, however, by Hood et al. (1998) who adapted Posner's spatial cueing paradigm (Posner, 1980) to test 3- and 4-month-old infants. In this paradigm, the spatial cue was a digitized, color image of an adult face with blinking eyes that subsequently shifted to the left or right. Infants oriented their attention faster to a peripheral target in the cued than non-cued direction, even though the gaze direction was not predictive of target location. This result was interpreted to suggest that 3- to 4-month-old infants can detect the direction of gaze and that this direction will influence the direction of their own attention.

Although these findings are suggestive of infants shifting attention in response to a perceived gaze shift, it is difficult to know whether infants were responding specifically to a shift in eye gaze or more simply to a translating stimulus, that is, pupils moving to the left or right. Farroni et al. (2000) tested this question directly by presenting 4- to 5-month-old infants with the same digitized face stimulus except that the face moved laterally and the pupils remained stationary, but appeared to move in the opposite direction because of relative motion. The results revealed that infants shifted their attention in the direction of the head movement suggesting that they were following the translatory movement of the head and not the gaze direction. Accordingly, it is still not clear whether young infants can respond to eye gaze independent of head orientation.

2.3.3 Point Following

Pointing is another deictic gesture used to reorient the attention of someone else so that an object or person becomes the shared focus of attention (Butterworth, 2003). Typically, it is identified by a stereotypical posture involving the index finger and the arm extended in the direction of a distal referent. Is there any evidence that young infants follow the direction of a pointing hand? Until recently it was assumed that point following did not emerge until close to the end of the infant's first year of development. A few early studies reported that 9-month-old infants follow a pointing gesture to nearby targets, and that by 12 months of age they follow the direction of a pointing gesture to more distant targets (e.g., Leung & Rheingold, 1981; Morissette, Ricard, & Decarie, 1995; Murphy & Messer, 1977). In addition, a more recent EEG study revealed that 8-month-old infants showed differential activation of a P400 ERP to pointing gestures that were congruent as opposed to incongruent with the location of a target (Gredebäck & Melinder, 2010). One problem with all of these studies is that younger infants were not tested, and thus it was not possible to establish at what age infants begin following a pointing gesture.

More recently, Daum, Ulber, and Gredebäck (2013) used a modified version of the spatial cueing paradigm pioneered by Hood et al. (1988) to test 10- and 12-month-old infants orienting responses to a pointing hand. Critically, the older but not the younger infants responded to the direction of the pointing hand, at least when it was accompanied by human speech. This finding thus suggests that point following does not emerge until close to the end of the first year, but a similar study by Rohlfing, Longo, and Bertenthal (2012) revealed a very different finding when testing 4- and 6-month-old infants' covert attention to a pointing hand. Unlike the preceding study, the sound of a human voice accompanied only the presentation of the attention-getting stimulus prior to the appearance of the pointing hand. The results of the first experiment revealed that infants oriented more quickly in the direction of the target when it was congruent as opposed to incongruent with the pointing gesture (even though the direction of the point was non-predictive of target location). Two follow-up experiments revealed that a slight movement of the hand was necessary, but not sufficient, for infants to shift their attention: faster responding to the congruent target was observed when the movement of the hand was in the same direction as the pointing finger, but there was no difference in responding to the congruent and incongruent targets when the movement of the hand was in the opposite direction of the target.

Before trying to reconcile the results from these two studies, it is necessary to consider two issues that may have undermined the validity of both studies. The first issue concerns whether infants were responding specifically to a pointing hand or were simply responding in the direction signaled by a pointing stimulus (i.e., social hypothesis vs. directionally oriented stimulus hypothesis). Neither study compared infants' responses to a pointing hand with their responses to a nonsocial stimulus, such as an arrow. This is a critical question to address since it is currently unknown whether infants are differentially sensitive to social and nonsocial spatial cues. The second issue concerns whether infants were likely to respond to the referent of the pointing gesture if the pointing hand did not disappear before the target appeared (this is a procedural manipulation introduced by Hood et al. (1998) to ensure that infants would disengage from an attractive face). In the case of a pointing stimulus, however, the question of disengagement is central to whether or not infants can follow a pointing hand, because infants may be interested in the hand per se, and thus not orient away from it (e.g., Amano, Kezuka, & Yamamoto, 2004; Butterworth & Grover, 1990; Woodard & Guajardo, 2003).

2.3.4 Testing Social Versus Nonsocial Models

To address these concerns, Bertenthal, Boyer, and Harding (2014) conducted an eye-tracking study with a similar spatial cueing paradigm, except that 4- and 6-month-old infants were tested with both a pointing hand and a foil, which preserved the same size and shape as the hand, but lacked featural details (Fig. 2.1). By comparing saccadic response times to these two stimulus cues, it was possible to determine whether infants' responses to a social stimulus were specialized. In addition, the stimulus cue in this study did not disappear when the target appeared (Fig. 2.2). As a consequence, it was possible to determine whether the stimulus to target onset asynchrony (SOA: delay between the onset of the stimulus cue and the target) would influence the likelihood of faster responding to the congruent target. In adults, faster responding to the cued target begins to dissipate after an SOA of more than 100 ms and is often no longer significant after 500 ms (Frischen et al., 2007). The reason for this effect is that a response time advantage occurs only if adults respond reflexively or automatically to the target, but following a 500 ms SOA they often have sufficient time to strategically select their response without any benefit for a reflexive response in the cued direction (Boyer & Bertenthal, 2012). When the SOA is only

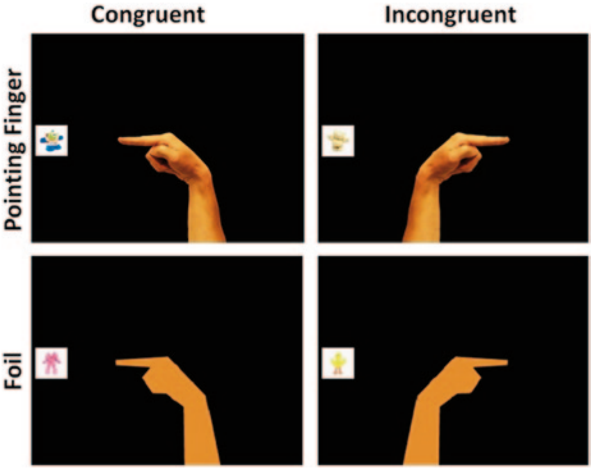

Fig. 2.1 *Digital images of the stimulus displays depicting the pointing hand and foil oriented in the direction (congruent condition) or the opposite direction (incongruent condition) of the target.* (Reprinted with permission from Bertenthal et al., 2014)

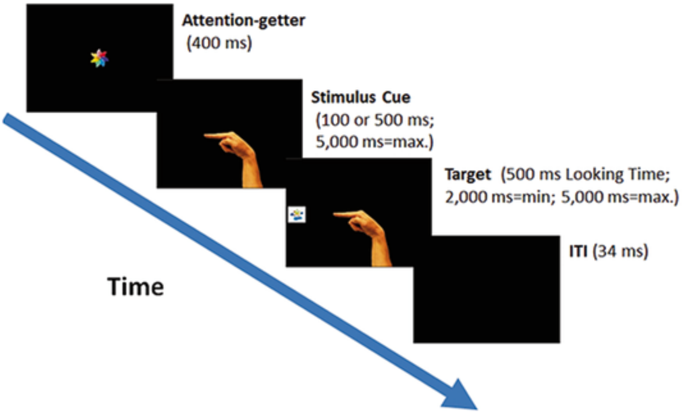

Fig. 2.2 *Sequence of stimuli presented on each trial with the gaze duration contingencies necessary for the appearance of the next stimulus.* Infants were coded as looking at one of the stimuli when their point of gaze landed in an area of interest that surrounded each of the stimuli. For the stimulus cue and target stimuli, minimum and maximum presentation durations are also listed. (Reprinted with permission from Bertenthal et al., 2014)

100 ms, a reflexive response will need to be inhibited if the target is not congruent (recall that the location of the target is not predicted by the direction of the pointing stimulus); thus, a longer response time associated with the incongruent target is a function of this inhibitory process. Infants were tested with both a 100 ms and a 500 ms SOA to determine whether the time course for their responding to a pointing stimulus was similar to the response time processes observed in adults.

An important innovation in this study was to use a gaze contingent paradigm such that each stimulus in the sequence appeared only after infants had attended to the preceding stimulus for a criterion period of time (see Fig. 2.2). A Tobii eye-tracking system (Stockholm, Sweden) in conjunction with E-Prime stimulus presentation software (Psychology Software Tools, Pittsburgh, PA) was used to implement these contingencies by recording and measuring gaze duration in real time. E-Prime was programmed to wait for a criterion gaze duration before displaying the next stimulus. This procedure ensured that infants would attend to each stimulus for the same amount of time on each trial before the next stimulus would appear. An added benefit to implementing this procedure was that infants became more task-oriented and were less likely to become distracted at the end of a trial. As a consequence, Bertenthal et al. (2014) were able to administer an average of almost 40 trials per infant, which significantly increased the power of their design.

The results revealed that 6-month-old infants responded faster to the congruent target appearing in the direction of the pointing hand stimulus at 100 ms SOA, but did not respond faster to the congruent target at 500 ms SOA (Fig. 2.3). By contrast, infants did not respond faster at either SOA to the target when the foil appeared as the stimulus cue. Four-month-old infants showed a congruency effect, but with less specificity. In essence, they responded faster to the congruent target at both

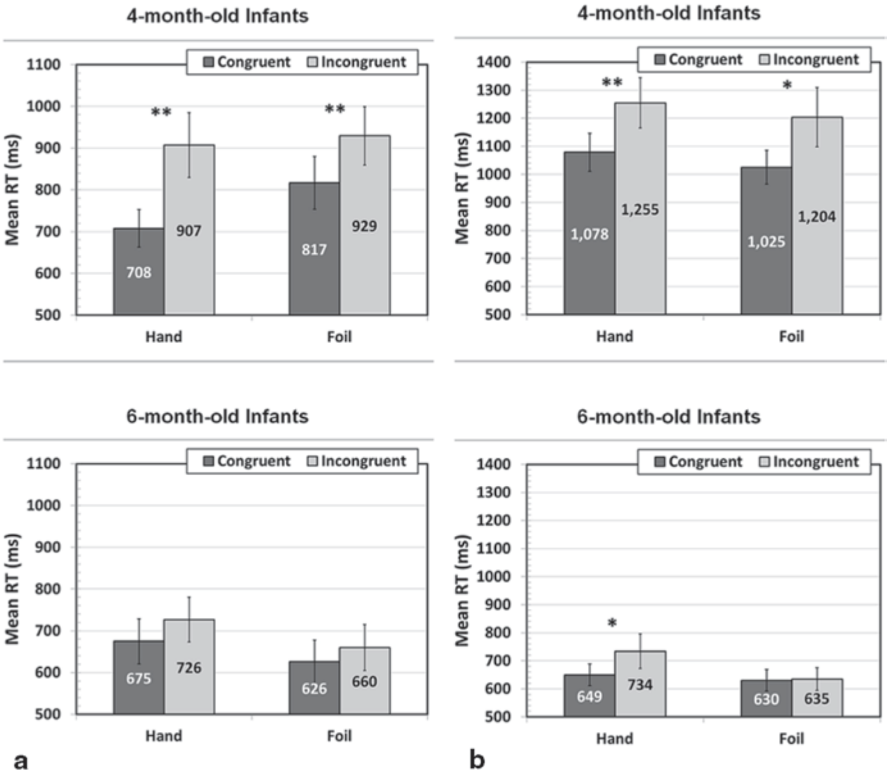

Fig. 2.3 **a** *Mean saccadic response times in Experiment 1 to the cued (congruent) and non-cued (incongruent) targets as a function of age and stimulus cue.* Error bars represent ± standard error of the mean; ***p* <.02; **p* <.04. **b** *Mean saccadic response times in Experiment 2 to the cued (congruent) and non-cued (incongruent) targets as a function of age and stimulus cue.* Error bars represent ± standard error of the mean; ***p* <.03; **p* <.05. (Reprinted with permission from Bertenthal et al., 2014)

SOAs independent of the stimulus cue. These results thus suggest that 6-month-old infants orient to a pointing hand differently than to a foil, presumably because their response is already specialized for a social stimulus. Moreover, it appears that the time course for reflexive orienting to a pointing hand is similar for infants and adults, in that infants, like adults, did not show a congruency effect at 500 ms SOA. By contrast, 4-month-old infants detect the direction of a pointing stimulus, but do not seem to differentiate between a social and nonsocial exemplar. The most straightforward interpretation for this result is that infants did not discriminate the pointing hand from the foil that shared the same size and shape.

In order to test this interpretation, a preferential looking experiment was conducted with the pointing hand, the foil, and an arrow. Infants were presented with pairs of stimuli on each trial, and the results revealed that both 4- and 6-month-old infants looked longer at the pointing hand than at the foil or the arrow, and also looked longer at the foil than at the arrow. Accordingly, the developmental shift observed in the previous experiment could not be attributed to differences in perceptual discrimination, but rather provides convergent evidence for suggesting that infants' responses to a pointing hand become specialized by 6 months of age. As such, this result is consistent with Johnson's model of interactive specialization, suggesting that the cortex becomes more specialized over time with regard to the stimuli that are processed by a specific neural network (Johnson 2011). This increased specialization is most likely a function of infants acquiring more experience with pointing hands through their social interactions with caregivers and others. According to this hypothesis, the reason that 4-month-old infants responded the same way to the pointing hand and foil is because both stimuli stimulated the same developing social attention network in the brain (Grossman & Farroni, 2009; Johnson, 2011). By 6 months of age, this network has become more specialized for social stimuli, and thus the response time advantage for congruent stimuli was restricted to only the pointing hand.

2.3.5 Point Following Versus Point Comprehension

Although these results converge with those reported by Rohlfing et al. (2012) to suggest that infants orient in the direction of a pointing hand by 4 months of age, Daum et al. (2013) suggest that infants do not orient in the direction of a pointing hand until 12 months of age. How can we reconcile these seemingly significant age differences? One possibility is that differences in the size and contrast of the stimulus cue and target are responsible, but we suspect that the reason is attributable to more than stimulus differences. In the two studies reporting that 4- and 6-month-old infants respond to the pointing hand by following the direction to the target, infants were able to orient their attention to the target without any knowledge of the social partner's mental state. It was sufficient for them to follow the direction of the point without any interpretation of its meaning. By contrast, infants in the Daum et al. (2013) study were shown a pointing hand with an accompanying speech act. The combination of the two stimuli together may have resulted in infants interpreting the stimulus not as a directional cue, per se, but rather as a communicative act requiring that infants understand the referential intention of the pointing hand (i.e., infants appreciate that the hand is attached to a social partner who is directing their attention to a specific referent). In essence, this difference was foreshadowed in the previous section (see section "Testing Social Versus Nonsocial Models") when discussing the distinction between following someone else's gaze and understanding the communicative intent of a gaze shift. The current results on pointing are in accord with those previous results on gaze following, which revealed evidence of gaze following by 3 months of age, but understanding a causal relation between gaze direction and target does not appear until sometime between 9 and 12 months of age (e.g., Johnson et al., 2007; Senju, Csibra, & Johnson, 2008).

Converging evidence for this interpretation comes from a series of studies investigating infants' comprehension as well as production of pointing (e.g., Deák et al., 2008; Liszkowski, Carpenter, Henning, Striano, & Tomasello, 2004; Liszkowski et al., 2007; Tomasello, Carpenter and Liszkowski, 2007). By 1 year of age, infants begin pointing to absent, or experientially defined, referents making it clear that they understand that pointing is not simply a cue for attracting another's attention to a specific object, but instead is a means to orient them mentally to some shared representation. Also, infants begin to show comprehension of pointing, which requires more than merely following the direction of a point; infants search for invisibly displaced objects in locations that are specified by an adult's point, and search even longer when the object is not found at the pointed location (Behne, Liszkowski, Carpenter, & Tomasello, 2012; Gliga & Csibra, 2009). An especially compelling example of how infants comprehend pointing in terms of a shared understanding was reported by Liebal, Behne, Carpenter, and Tomasello (2009) who showed that 14- and 18-month-old infants interpreted an adult's pointing gesture differently depending on whether or not this individual had been involved with the infant in a previous activity. Taken together, these findings suggest that infants are not merely following the direction of a pointing gesture, but instead understand the communicative intent of the actor. By contrast, great apes will follow the direction of a point to the location of some hidden food, but will generally not search inside the container for food because they do not make the inference that the point is communicating the location of food (Miklosi and Soproni, 2006). We predict that 6-month-old infants would respond in a similar manner to great apes, because they, too, do not understand the communicative intent of the point.

2.3.6 Development of Joint Attention

In sum, infants follow the direction of a pointing hand within a month of being able to follow a gaze shift. For both of these stimuli, movement is necessary, but not sufficient, to trigger an orienting response. It thus seems unlikely that gaze cueing is privileged for orienting infants' attention; rather, gaze cueing, head orientation, body posture, and pointing are all likely candidates for triggering shifts of attention, and infants' responses to these behaviors become more specialized with age and experience. At least until 6 months of age, infants are capable of following the direction of an eye, head, or body movement, but they have not yet developed a shared understanding with the other person as to the motivation for this deictic gesture. According to some theorists (e.g., Carpenter et al., 1998; Tomasello, 2008), this shared understanding does not emerge until infants begin to understand others' goals and intentions, sometime between 9 and 12 months of age. Although this view is consistent with much of the extant data, it does little to explain how joint attention develops. It is assumed that this behavior develops with the emergence of the necessary prerequisite social–cognitive skills, but without knowledge of *how these* *skills develop* this explanation is far from complete. As such, the prevailing view of the development of joint attention seems fragmented and discontinuous.

As an alternative, we favor a model suggesting a more continuous progression in the development of joint attention (cf. Bertenthal et al., 2014). The early development of point or gaze following establishes a foundation for a boot-strapping process by which infants learn about the intentions of others from opportunistically directing their attention to others' deictic gestures and the co-orientation of visual attention that ensues (cf. Moore & Corkum, 1998; Triesch, Teuscher, Deák, & Carlson, 2006). In essence, these encounters offer an opportunity for infants to learn that following another's deictic gesture leads to their attending to some person or event of interest to them. These encounters become more and more frequent with development, especially with the decline of dyadic interactions. As infants are exposed to these interactions repeatedly on a daily basis, the probability of their encoding a relation between a deictic cue and a distal referent will increase, and so will their shared understanding of others' behaviors (e.g., motoric, verbal, affective) in these triadic social interactions. Accordingly, we contend that the relation between attention and social understanding is bidirectional. As infants attend more to the social cues in triadic interactions, their attention will tutor their social understanding, but at the same time their attention will be directed to the relevant cues by their social–cognitive understanding.

2.4 Contributions of Motor Experience to Action Understanding

2.4.1 Relation Between Observation and Execution of Actions

In spite of the voluminous research on social–cognitive development during the first year, our understanding of how infants' social cognition develops is still fairly limited. Most theorists agree that this knowledge emerges with infants' transactions in their social environment, but there is little consensus regarding the mediators of this development. In recent years, various proposals have emerged, suggesting that infants' understanding of others' actions is facilitated by their linking the perception and execution of actions (e.g., Bertenthal & Longo, 2008; Woodward & Gerson, 2014).

Infants learn a great deal about themselves, other people, and their surroundings from observing the effects of their own actions as well as those of others (e.g., Bertenthal & Campos, 1990; Lock & Zukow-Goldring, 2010). Moreover, some theorists suggest that motor experience is necessary for not only producing but also for learning about goal-directed actions (e.g., Rakison & Woodward, 2008; Woodward, 2009). For instance, infants interpret others' reaching actions as goal directed by 5–6 months of age (Woodward, 1998), which is roughly the same age they begin to successfully reach for distal objects (Bertenthal & von Hofsten, 1998. If reaching experience is provided with Velcro-covered sticky mittens, then infants interpret others' reaching actions as goal directed at 3 months of age, even before they are able to reach on their own (Sommerville, Woodward, & Needham, 2005). Also, the sorts of grasps 6-month-old infants are capable of performing predict their ability to differentiate others' grasps (Daum, Prinz, & Aschersleben, 2009). Nine-month-old infants who are already capable of pointing are more likely to understand the referent of a point (Brune & Woodward, 2007), and 10-month-old infants capable of pulling a cloth to retrieve a toy are more likely to understand the means–end structure of someone else performing the same hierarchical goal-directed action (Sommerville & Woodward, 2005). Although the preceding studies support the thesis that motor experience is necessary for action understanding, there are also some exceptions to this generalization (e.g, Boyer, Pan, & Bertenthal, 2011; Hofer, Hauf & Aschersleben, 2005; Daum et al., 2009). Thus, it is more parsimonious to conclude that there is a bidirectional relation between the perception and production of new actions in development (e.g., Bertenthal, 1996; Hauf, 2007).

The preceding evidence is all consistent with theories suggesting a direct link between the perception and execution of actions. This proposal dates back to James's (1890) and Greenwald's (1998) ideomotor theories, which were more recently updated by Prinz's common coding theory (1998). According to this theory, the perception and production of actions share overlapping representations, and thus one process facilitates, or interferes with, the other when they occur close together in time (Hommel, Musseler, Aschersleben, & Prinz, 2001). The discovery of mirror neurons in nonhuman primates and homologous findings in humans offer further support for a direct mapping between the observation and execution of actions (e.g., Decety et al., 1997; di Pellogrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). Although the activation of this motor representation does not typically result in overt movements, the cortical regions involved in the planning of the movement and the intended goal are activated. As such, the observation of the action is mapped directly to its motor representation consisting of both the movement plan and the goal. This results in a shared representation enabling the observer to understand how he or she would perform the same action (e.g., Gallese and Goldman, 1998; Prinz, 1997; Rizzolatti, Fogassi and Gallese, 2001).

2.4.2 Representation of Movements Versus Goals

In considering how motor experience contributes to action understanding, it is important to consider that actions are represented at multiple, hierarchically nested levels ranging from specific muscle synergies to more abstract distal goals (Bertenthal & Longo, 2008). It is often assumed that the direct matching that occurs between the observation and execution of actions occurs exclusively at the level of the goal or the effects of the action (e.g., Cook, Bird, Catmur, Press, & Heyes, 2014;

Wohlschläger, & Bekkering, 2003). Indeed, this is consistent with early descriptions of mirror neuron properties, which reported that pantomimed actions (e.g., miming a precision grip in the absence of an object) and intransitive actions (e.g., tongue protrusion) did not elicit mirror neuron responses (Gallese et al., 1996). Similarly, it has been suggested that infants code actions at this same level of analysis, because goals can be represented more abstractly than movements, and thus infants can generalize their representations more readily to others' goal-directed actions even if the specific movements vary (Woodward & Gerson, 2014). For instance, infants learn to generalize one instance of a goal-based action (e.g., goal-directed reaching) to a novel situation in which they observe someone reaching with a mechanical claw, as long as their grasping actions co-occur with the claws' grasping and releasing toys (Gerson & Woodward, 2012).

In spite of the attractiveness of this logic, we wish to caution against dismissing prematurely the importance of movements per se in mapping the observation of actions to their execution. In a developing system such as the human infant, it is sometimes difficult to determine whether the rate-limiting factor is motor coordination or the identification of the goal. For example, 5-month-old infants are incapable of maintaining a balanced sitting posture, yet, biomechanical measurements of their postural sway reveal that their behavior is already goal directed (Bertenthal, Rose & Bai, 1997). Accordingly, infants at this age may lack the necessary motor representation to perceive why someone else is, or is not, sitting in a balanced posture, but it is not because they lack a representation of the goal, rather it is because their movements are not yet sufficiently coordinated; thus the representation is insufficient at the level of the movements, not of the goal.

Consistent with this view, some theorists suggest that, at least in humans, movements may play a larger role in the representation of perceived actions than had previously been supposed. Rizzolatti et al. (2001), for example, speculated that two distinct "resonance mechanisms" may underlie imitation in humans: a high-level resonance mechanism coding action in terms of goals and a low-level resonance mechanism sensitive to the movements constituting an action. Lyons, Santos, and Keil (2006) similarly suggested that the mirror system in monkeys may code perceived actions only in terms of their goals or underlying intentions, whereas the human mirror system codes actions more flexibly and at multiple levels of abstraction, both in terms of goals and the manner in which those goals are achieved. Some early evidence supporting this interpretation comes from a series of studies by Gangitano, Mottaghy, & Pascual-Leone (2001, 2004), who applied transcranial magnetic stimulation (TMS) to the motor cortex as adult participants watched a hand reach and grasp an object. By manipulating when in the time course of the grasp TMS was applied, they demonstrated that the motor-evoked potentials recorded from arm muscles varied systematically with the changing size of the finger aperture. This finding thus suggests that the mental simulation of the observed action included the manner in which the action is performed over time and does not exclusively represent the goal or end state.

Behavioral evidence for this same conclusion comes from a series of studies with adults testing automatic imitation of intransitive actions not involving a goal object, or at least holding the goal constant (e.g., Bertenthal, Longo, & Kosobud, 2006; Boyer, Longo, & Bertenthal, 2012; Brass, Bekkering, & Prinz, 2001). For example, Longo, Kosobud, and Bertenthal (2008) reported that participants responded faster to the tapping movement of an index or a middle finger when they pressed a key with an anatomically matching finger, regardless of whether the finger moved in a biologically possible or impossible manner. If, however, participants were primed to expect both natural and unnatural movements before beginning the experiment, then the compatibility effect was eliminated in the biologically impossible movement condition. In both conditions, there was an identical intransitive goal, which was to depress a key with a matching finger; nevertheless facilitation was only observed if participants were not primed to focus their attention on the manner of movement. These findings are thus illustrative of how actions can be represented at multiple levels: When participants were not cued, the observed finger tapping facilitated the response of the matching finger because actions were represented in terms of goals; when cued, actions were represented in terms of movements and, since the impossible finger movement was not represented within the observer's motor repertoire, there was no activation of a corresponding response.

In sum, these findings with adults confirm that observed actions are automatically mapped to the motor system at the level of both the goal and the movement. This mapping is a function of a shared representation for the observation and execution of the action, but it is also a function of whether the observer focuses attention on the movement or the goal. In the remainder of this section, we will discuss converging evidence for infants motorically simulating, or covertly imitating, the reaching movements that they observe. Critically, the likelihood of infants motorically simulating the observed actions by the experimenter will depend on how attention is deployed during the experiment.

2.4.3 Covert Imitation and Infants' Search Errors

One of the best known paradigms for studying infants' cognitive development is the Piagetian A-not-B search task (Harris, 1975). Infants are seated in front of two hiding locations and observe an experimenter hide an object in one of these locations (i.e., A-location) and then are given an opportunity to search for the hidden object (Fig. 2.4). By 9 months of age, infants are consistently successful in searching for the object over repeated trials. If, however, after a few trials the object is hidden in the opposite location (i.e., B-location), infants err by searching in the previously correct A-location. There are numerous explanations for this search error (see Bremner, 2010 for a review), but a number of recent explanations emphasize the role of repeated reaching and the development of a perseverative response (e.g., Diamond, 1991; Marcovitch, & Zelazo, 1999; Smith, Thelen, Titzer, & McLin, 1999). In essence, this response is a function of the history of activation by the motor system (Thelen, Schöner, Scheier, & Smith, 2001), and thus any experience that might bias the activation of the motor system should induce a similar result (Longo

Fig. 2.4 *Infant searching for toy in one of the two hiding wells*. (Reprinted with permission from Longo & Bertenthal, 2006)

& Bertenthal, 2006). If infants are capable of mapping observed actions to their motor responses and thus motorically simulating these actions, then the same search error on the B trial should be revealed even when infants only observe someone else searching for the hidden object on the A trials.

Longo and Bertenthal (2006) tested this hypothesis by allowing 9-month-old infants to only observe the experimenter hiding and finding the object on the A trials before allowing them to search on the B trial. Overall, the results confirmed their hypothesis, but there was a caveat. A significant number of infants showed the search error after they observed the experimenter perform an ipsilateral reach (hand and object are located on the same side of the body), but infants searched randomly following a contralateral reach (hand contacts an object located across the body midline). This finding was perplexing to many because of the preponderance of data and theories suggesting that mirroring involves a shared representation of the goals or effects of the actions, but not of the movements per se. If, however, infants were responding exclusively in terms of observed goals, then there should not have been a difference in responding as a function of reach type because the goal in both conditions was the same (i.e., retrieve the hidden object). Given the results from this study, it seems reasonable to conclude that there is a tendency in infants to code or covertly imitate the movements as well as the goals of observed actions.

2.4.4 Ipsilateral Versus Contralateral Reaching

Why should infants be more likely to covertly imitate or simulate the actions associated with an ipsilateral than a contralateral reach? Longo and Bertenthal (2006) proposed that this difference was attributable to a delay in the development of contralateral relative to ipsilateral reaching. There are reports dating back to Head (1920, 1926) that aphasic patients, when asked to imitate, frequently failed to cross the body midline, performing an ipsilateral when a contralateral movement was modeled. Although Head (1920, 1926) considered this error a serious sign of neurological insult, this ipsilateral bias has been observed in infancy as well as in older children. The development of contralateral reaching generally lags 2–4 months behind ipsilateral reaching (Bruner, 1969, Morange & Bloch, 1996). If action simulation is related to motor experience, then we would expect a greater number of infants to show errors in the ipsilateral, as opposed to contralateral, condition, because the contralateral motor representation would be less well developed, and thus less likely to bias the reach.

Although the evidence for a lag in the development of contralateral reaching is compelling, there is also the possibility that infants were less likely to selectively focus their attention during contralateral reaches. If this were true, then, by analogy with the adult study comparing possible and impossible biological movements, we would expect a greater likelihood of search errors after increasing infants' attention to contralateral reaches. Recently, Boyer and Bertenthal (in press) tested this possibility by first priming infants to contralateral reaches before testing them. During a 2-min familiarization phase, infants observed an experimenter reach repeatedly for toys with only his contralateral hand, and then he searched for the hidden toys on the A trials using only his contralateral hand. Unlike the results from the preceding experiment, a significant number of infants searched incorrectly in this experiment. It is noteworthy that during the familiarization phase, the experimenter ensured infants' direct attention by including multiple ostensive cues, such as direct eye contact, infant-directed speech, and contingent responding. This may be at least one of the reasons why observational learning without any active participation by the infant was more successful in this experiment than that reported in previous studies (e.g., Sommerville, Hildebrand, & Crane, 2008). In a follow-up experiment, a new group of infants was tested the same way after they were familiarized to only ipsilateral reaching. Even though the goal was the same in this new condition, infants did not search significantly more often than chance at the incorrect location. It thus appears that focusing infants' attention on the movement, but not the goal of an action, will increase the contribution of the movement representation toward inducing a search error.

2.4.5 Predicting the Goal of an Action

Just to be clear, the preceding discussion is not meant to suggest that infants are incapable of mapping observed actions at the level of goals; rather, it is to suggest that they also map actions at the level of movements. In the case of observing ipsilateral and contralateral reaching, recent research from our laboratory confirms that infants represent not only the movements but the goals as well. A key insight for understanding the logic behind this research is that it is essential for actions to be planned prospectively if they are to be performed in a fluid and flexible manner (Bertenthal, 1996; Bertenthal & von Hofsten, 1998; von Hofsten, 1980). This prospective component of an action enables adults to not only predict the goal of their own actions but also the goal of others' actions, thus providing converging evidence that observed actions are mapped to their motor representations (Flanagan & Johansson, 2003). Recent findings with infants suggest that they begin to predict the goal of an action sometime between 6 and 12 months of age, depending on the complexity of the action. For example, infants predict the goal of a simple reaching action as early as 6 months of age (Kanakogi & Itakura, 2011), but they only begin to predict the goal of placing an object in a container around 12 months of age (Falck-Ytter, Gredebäck, & von Hofsten, 2006). These results suggest a general correspondence in age between the emergence of goal prediction for a specific task and the complexity of the motor behavior, but most of the evidence is correlational and indirect (but see van Elk, van Schie, Hunnius, Vesper, & Bekkering, 2008 for an exception).

Unlike most previous studies, Barton and Bertenthal (2013) were able to manipulate motor experience directly by testing infants' goal prediction during both ipsilateral and contralateral reaching. If there is a functional relation between motor experience and goal understanding, then goal prediction during ipsilateral reaches should be observed at an earlier age than that during contralateral reaches. Infants between 6 and 12 months of age were tested with a Tobii TX300 eye-tracking system while observing an actor sitting at a table with fingers tapping while the hands were aligned at the body midline (Fig. 2.5). On each trial, the right or left hand would reach either ipsilaterally or contralaterally toward a lid located to the left or right of the actor; once the lid was grasped and lifted a moving and sounding stimulus reward would appear at that location. The sequencing of the stimuli was gaze contingent, which enabled the researchers to present, on average, 33 trials. If infants shifted their gaze to the correct lid prior to the hand contacting it, they were credited with predicting the goal on that trial. As can be seen in Fig. 2.6, the proportion of predictive trials increased with age for both ipsilateral and contralateral reaches. Nevertheless, infants were more likely to predict the goal on ipsilateral than on contralateral trials, at least through 10.5 months of age.

To confirm that the development of infants' goal prediction skills were systematically related to motor experience, infants were also tested on a reaching task. The likelihood of contralateral reaching increased with age and also correlated with the probability of goal prediction. More importantly, the likelihood of contralateral reaching continued to covary with contralateral goal prediction after partialling out age and ipsilateral reaching. As such, these results suggest not only a relation between the development of goal prediction and motor experience, but also that

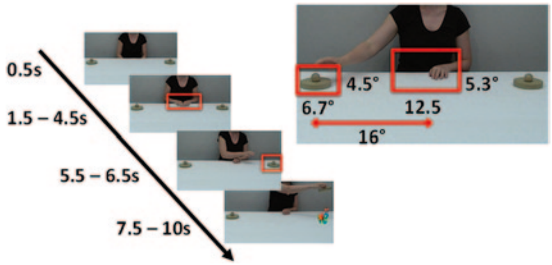

Fig. 2.5 *Sequence of actions appearing on each trial.* The hands continued to tap on the table until infants looked at them for 500 ms. Goal prediction was defined as the eyes entering the area of interest surrounding the lid before the hand touched the lid

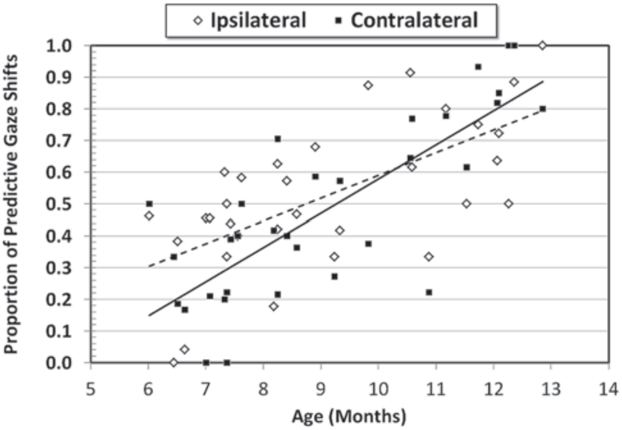

Fig. 2.6 *Mean gaze shift times from the hands to the lid.* Positive gaze shift times indicate that gaze anticipated the hand grasping the lid; negative gaze shift times indicate that gaze lagged behind the hand grasping the lid

it is specific to the type of movement (i.e., ipsilateral vs. contralateral reaches). Strictly speaking, some third variable could account for improvements in both the prediction and production of contralateral reaches, but it is difficult to imagine any variable aside from motor experience that might mediate differences in the development of goal prediction as a function of reach type.

2.4.6 Observation–Execution Matching of Nonhuman Actions

Thus far, we have reviewed evidence showing that action observation is linked to action understanding at the level of both movements and goals. One unresolved issue in the literature is whether the process responsible for linking the observation and execution of actions is limited to human actions, or whether it generalizes to nonhuman and mechanical actions. The majority of evidence with adults suggests that the observation of robotic or mechanical actions results in less activation of the motor system, and thus, at the very least a diminished neural, as well as behavioral, response (e.g., Kilner, Paulignan, & Blakemore, 2003; Press, Bird, Flach, & Heyes, 2005; Tai, Scherfler, Brooks, Sawamoto, & Castiello, 2004). This result is typically interpreted as supporting the hypothesis that an observation–execution matching system is limited to actions within the motor repertoire of the observer, or that the observer codes the action at the level of its intention, which does not exist in nonhuman agents (e.g., Calvo-Merino, Glaser, Grezes, Passingham, & Haggard, 2005; Teufel, Fletcher, & Davis, 2010).

According to either of these interpretations, infants should be unlikely to automatically activate a motor response when observing a nonhuman agent, such as a mechanical claw. Indeed, previous research by Woodward (1998) revealed that infants' understanding of a functional relation between a goal and an action was not generalized to situations involving either an inanimate rod or a mechanical claw. In spite of this finding, Gerson and Woodward (2012) reported that 7-month-old infants were able to identify the goal of an action performed by a claw-shaped tool after receiving some active experience using the tool to grasp objects. By contrast, they did not identify the goal after merely interacting with the tool or observing the experimenter use it to move objects. The authors concluded that it was necessary for infants to motorically experience these actions and compare them to observed actions for infants to understand the goal structure of the event. In this case, it seems reasonable to conjecture that observational learning was not sufficient, because the actions necessary for moving these tools were not yet incorporated within their motor repertoire. Still, there are exceptions to this conclusion suggesting that observation of claws without motor experience is sufficient to induce motor understanding (Gerson and Woodward, 2014; Hofer et al., 2005).

How can we reconcile these seemingly contradictory results? As we previously suggested, all types of observational learning are not the same and it is especially important to guide infants' attention with ostensive cues if they are to benefit from the modeled behavior (Boyer & Bertenthal, in press; Csibra, & Gergely, 2009). Boyer et al. (2011) offer some preliminary evidence for this prediction. They tested 9-month-old infants in the observational version of the A-not-B paradigm used by Longo and Bertenthal (2006), except that the experimenter was replaced by two mechanical claws that mimicked the actions of the experimenter in the object hiding experiment (see Fig. 2.7).

Three experiments were conducted with each successive experiment providing more claw experience before testing began. The first experiment provided infants with no claw experience before testing, and the results revealed that infants were just as likely to search in the correct, as opposed to, the incorrect location. At the beginning of the second experiment infants were familiarized with the experimenter and the claws by observing the experimenter handle the claws and other toys for approximately 2 min. During this familiarization phase, the experimenter used

Fig. 2.7 *Infant observing the mechanical claws grasp the toy (Experiment 1)*. (Reprinted with permission from Boyer et al., 2011)

ostensive cues, including infant-directed speech and contingent responses, to attract infants' attention, but the results were no different than those reported in Experiment 1. At the beginning of the third experiment, infants observed the experimenter use the claws to retrieve toys that were beyond his reach for approximately 2 min. Once again, the experimenter engaged the infant with ostensive cues, but this time the intent was to direct attention not to the experimenter himself, but rather to the actions performed by the claw. Unlike the results from the first two experiments, a significant number of infants now searched incorrectly on the B trial. These results are significant for two reasons:

(1) Woodward and Gerson (2014) suggest that infants are capable of understanding the goal-directed actions of tools if they receive active experience with them. This experience enables infants to store the goal structure of the action so that a mapping can be formed between the observation of the tool and its motor representation. In the case of the claws, however, infants were unable to gain active experience because they were too large to manipulate, and also representing the object-directed goal would not bias them to search in the incorrect location because the goal was identical in both locations (i.e., retrieve the hidden object). Boyer et al. (2011) suggest that at least with regard to motor simulation, which is necessary for inducing the search error, it is not just the goal or the effect of the action, but rather the *means–end relation* that is critical for infants' action understanding. As a function of the familiarization phase, infants gained experience observing how the claws achieved the end result of retrieving the toys, not with a hand, but rather with a tool controlled by the hand. As a consequence of observing an association between the claw and the hand controlling it, infants were inclined to generalize this observed action to their stored representation of goal-directed reaching (cf. Boyer et al., 2011). Once infants were primed during this familiarization period, they were inclined to develop a response bias to the A-location during testing just as they had in the previous studies when observing a person hiding and finding the displaced object.

(2) Even though infants did not actively manipulate the claws, they appeared to learn from observing the experimenter. In this case, learning benefited from the experimenter not performing the same identical action repeatedly, but rather varying both the location of the toy and the hand used to retrieve it. Variation and selection from multiple examples is a well-established mechanism for facilitating learning (e.g., Bertenthal, 1999; Siegler, 1994). This variation is easy to overlook when comparing active to passive experience, but infants' are not yet well coordinated and thus virtually any action will vary in one or more details each time it is executed. Accordingly, infants are assured to receive some variable experience when performing actions themselves, but this will be less likely when modeled by an adult unless the variation is intentional. In addition, infants benefited from the experimenter structuring the situation, so that they could coordinate their attention to both the experimenter's face and his goal-directed actions. Infants tended to alternate their attention back and forth between the experimenter and the objects that were grasped by the claws.

> In other words, they engaged in joint attention, which we hypothesize significantly contributed to the likelihood of infants mapping the actions of the claw to their own reaching actions.

Although we can only speculate at this time, we hypothesize that another reason why observational learning leads to inconsistent results with regard to action understanding is that it is facilitated by joint attention, which is not controlled in these studies. In the next section, we discuss in more detail the processes by which joint attention develops and contributes to infants' understanding of a social partner's actions.

2.5 Coordination of Attention Between Infants and Their Social Partners

2.5.1 Attention to People and Objects

As previously discussed, infants begin to engage in triadic interactions involving joint attention and some shared understanding of mental states around 9–12 months of age. In order for them to develop this shared understanding, they must also learn to coordinate their attention to their social partner with their attention to objects. Although it is well established that this developmental transition occurs, little is known about how an early preference for faces gives way to a more distributed view of the social world that includes not only faces, but bodies and actions, as well as objects. In general, attention is the front-end of encoding and interpreting all stimulus information encountered in the environment, and thus it is essential for not only learning to recognize and discriminate faces, but the actions of people as well. How do infants decide where to look from moment-to-moment when confronted with not only a dyadic partner but also an assortment of objects, other people, and events in their optic arrays? Early on, infants' orienting to stimuli in the environment is primarily under exogenous stimulus-driven control, but over time they begin to also develop endogenous control over their attention (Johnson, 2011; Mundy & Jarrold, 2010). As such, they begin modulating their attention in response to the actions of others as well as the context. Indeed, this is exactly what is necessary for infants to follow the gaze direction of a social partner during shared attention. If infants could not modulate their attention, then they would simply continue to be guided by their bias for faces, but the development of joint attention suggests otherwise.

Although there has been considerable research investigating the social cognitive prerequisites for joint attention, such as shared intentions or common ground (Tomasello, 2008), much less is known about how, and when, infants begin to coordinate their social attention between faces, actions, and objects. One reason for the sparseness of relevant findings is that most studies obviate the need for infants choosing between different stimulus cues. As previously discussed, infants are typically presented with a specific sequence of events, such as an actor eliciting an infant's attention, and then looking or pointing in a specific direction followed by an object appearing in either that direction or the opposite direction; infants merely have to attend to the stimuli in the order they appear and not choose when, and what, to look at (e.g., Bertenthal et al., 2014; Daum et al., 2013). In more naturalistic situations, such as an infant interacting with a caregiver in a cluttered room among a set of objects over a more extended period of time, the caregiver might alternate between gazing at the child and the objects, and jointly playing with those objects or showing them to the child. The question then becomes, how much are infants' looking behaviors guided by attention to the face, or by attention to the actions of the caregiver, the orientation of her face, her body posture, or changes in her object-directed actions?

Recent advances in infants' eye-tracking research offer important opportunities for systematically investigating how infants distribute their attention to social and nonsocial stimuli. Most studies, however, still rely on presenting highly scripted and repetitive actions to infants in experimental paradigms involving a digital image, or movie, of a social partner looking or reaching toward an object following an ostensive cue, such as eye contact with the viewer (e.g., Senju & Csibra, 2008; Daum et al., 2013). Frank and colleagues (Frank, Vul, & Johnson, 2009; Frank, Vul, & Saxe, 2012) have made some important progress in studying infants' and toddlers' social attention to more naturalistic visual scenes. In one experiment, the visual fixations of infants and toddlers between 3 and 30 months of age were recorded while viewing short videos of objects, faces, children playing with toys, and complex social scenes involving more than one person (Frank et al., 2012). The youngest infants looked primarily at faces and eyes, but older infants and toddlers distributed their gaze more flexibly, and looked more at the mouth and also the hands, especially when the hands were engaged in actions on objects. Also, the distribution of fixations differed not only as a function of age, but as a function of specific actions. For example, older children, in particular, looked at the mouth more often when the actor was smiling or talking (even though there was no accompanying sound).

A more recent study by Elsabbagh et al. (2014) also studied infants' relative distribution of fixations to the eyes and mouth when viewing a social partner with eyes, mouth, or hands moving or expressing multiple communicative signals (e.g., peek-a-boo). Consistent with previous studies, infants between 7 and 15 months of age looked at the eyes more than the mouth, but this difference was contextually modulated such that when only the mouth moved infants looked more at the mouth than when only the eyes moved. Taken together, these few studies suggest that by sometime during the latter half of the first year infants' social attention is controlled by both stimulus-driven factors, such as eyes and faces, and more endogenous or goal-directed factors that can exert control of looking behavior.

2.5.2 Effects of Salience and Context on Attention

Recently, Boyer, Harding, and Bertenthal (2015) conducted an eye-tracking study to better understand how infants dynamically select and synchronize their focus of attention during ongoing social interactions with people and objects. This dynamic

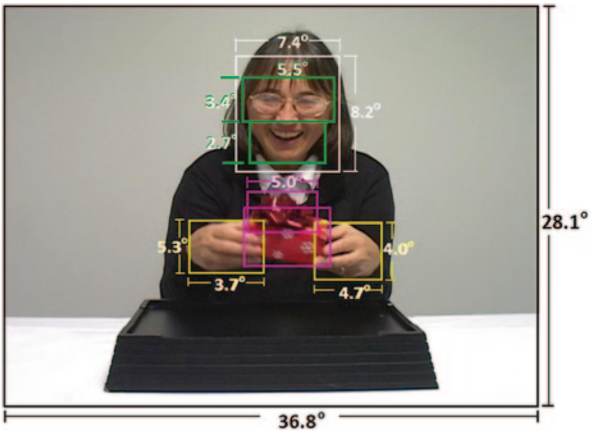

Fig. 2.8 *Screenshot from one of the stimulus videos with an overlay of the AOIs*. The numerical dimensions of each AOI correspond to their mean size based on all frames of the video

selection of where to look is a prerequisite for joint attention, and is facilitated by infants following their social partner's head orientation and eye gaze. From this experience they learn that during direct gaze there is an opportunity for eye contact and communication with the social partner, whereas during averted gaze there is an opportunity for joint attention toward another person or object (e.g., Johnson, 2006; Triesch et al., 2006). If, however, the social partner is waving her hands, or manipulating an object, while looking at the infant, the likelihood of the infant establishing eye contact with the social partner decreases. In typical social interactions, the cues for where to look will often compete and this is especially true for young infants outside the laboratory.

Unlike the studies conducted by Frank and colleagues (2009, 2012), the stimuli used by Boyer et al. (2015) were not movies of people or cartoon characters shown from a third-person perspective such that infants were simply watching a movie. Instead, these stimuli were created to show different actors socially engaged with the viewer from a first-person perspective. Although the stimuli were videos, they were designed to simulate naturalistic interactions that could occur between an adult and an infant. Each of 16 videos presented one of five female actors talking and demonstrating a sequence of simple actions, such as putting a shirt on a stuffed animal. Contrary to conventional wisdom, a few recent studies suggest that infants do not always look at the social partner's eyes or face during joint attention; instead, they sometimes focus on sharing attention to the same goal-directed actions (Deák, Krasno, Triesch, Lewis, & Sepeta, 2014; Franchak, Kretch, Soska, & Adolph, 2011; Yu & Smith, 2013). Thus, it was important to include not only people and their gestures but also object-directed actions. Three age groups were tested: 8-month-old infants, 12-month-old infants, and adults. Dynamic areas of interest (AOIs) were created around the faces, hands, and objects shown in each video in order to quantify the proportion of time that participants directed their attention to theoretically significant portions of the stimulus (see Fig. 2.8). Over the course of each video, participants' would continuously change their focus of attention from one AOI to another, but there was considerable consistency in how attention was dynamically allocated (Fig. 2.9).

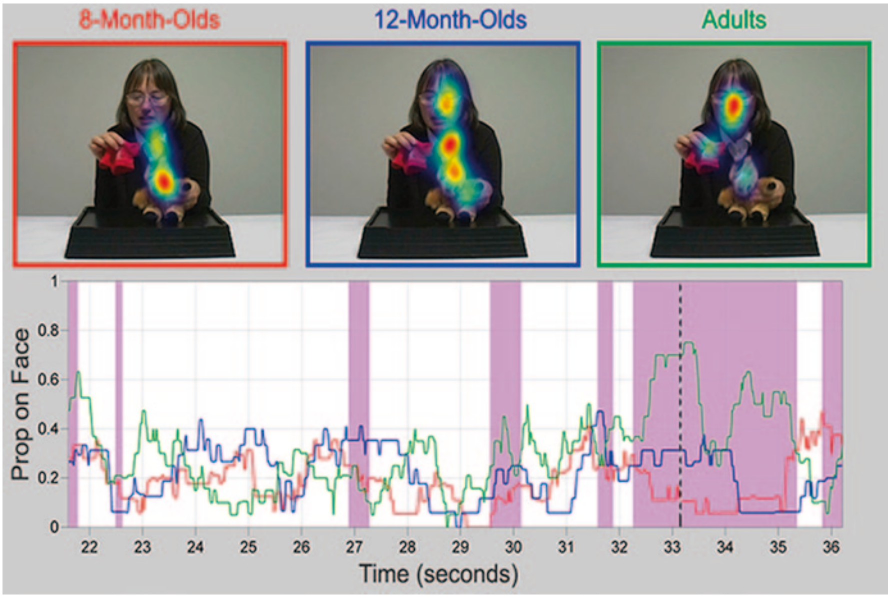

Fig. 2.9 *Top panels. Heat maps of the mean likelihood of looking at a specific location on one frame of one of the videos for each of the three age groups.* This frame occurred 33.2 s. after the video began. *Bottom panel. Proportion of participants in each age group looking at the face on each frame (red: 8-month-old infants; blue: 12-month-old infants; green: adults).* The shaded regions correspond to direct gaze by the actor, and the non-shaded regions correspond to object-directed gaze by the actor. The dashed vertical line corresponds to the time of the video frame depicted in the top panel

Overall, infants and adults showed similar patterns of looking at the stimulus information with greatest attention directed toward objects, followed by attention to faces and hands (Fig. 2.10). As such, this result contrasts with reports from many previous studies suggesting a face preference (e.g., Frank et al., 2012; Jones & Klin, 2013). It is very likely that these differences are at least partly attributable to variations in the stimuli, including whether or not actions were included, people were seen from either a first- or a third-person perspective, and eye gaze alternated between looking at the viewer and directing attention to other objects in the scene. This is but one of many reasons why simulating more natural viewing conditions is essential to a comprehensive study of social attention (see Nasiopoulos, Risko, & Kingstone, Chap. 5, this volume, for further discussion of this issue).

An important innovation of this study was to also assess how visual attention was contextually modulated. For example, both adults and 12-month-old infants looked more at faces when actors' gaze was directed at the viewer, and looked more at objects when actors' gaze was directed toward the objects (see Fig. 2.11). Likewise, all three age groups looked more at objects when they were manipulated by the actor than when they were not held, but only the adults looked more at faces when the objects were not held. Taken together, these results suggest that 8- to 12-month-old

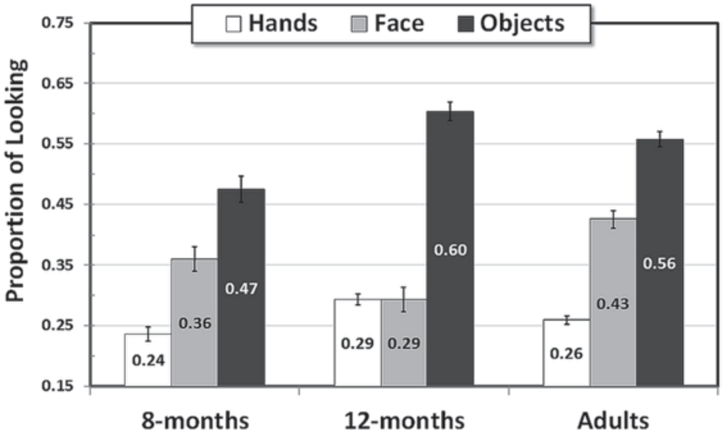

Fig. 2.10 *Mean proportions of each trial participants directed attention to the hands, face, and objects as a function of age.* Error bars represent +/− standard error of the mean

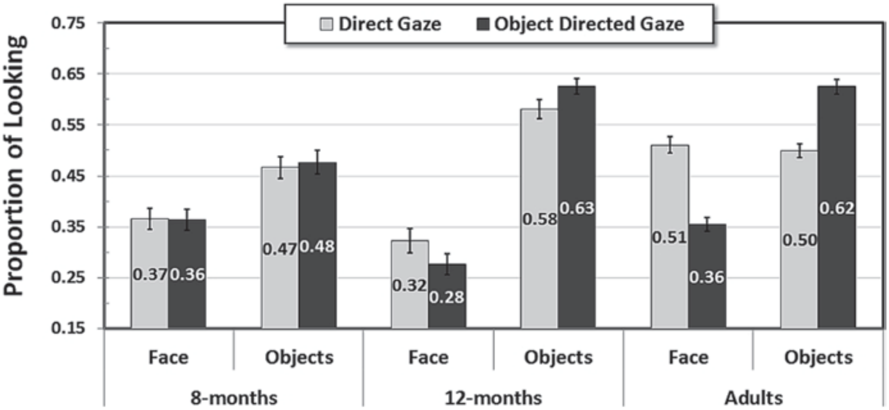

Fig. 2.11 *Mean proportion of each trial participants directed attention to the face and objects as a function of age and actors' direct versus object-directed gaze.* Error bars represent +/– standard error of the mean

infants' attention to the social world is not only mediated by the meaningfulness of faces and objects, but also modulated by their knowledge of social cues and actions. Through repetitive interactions with their caregivers and other social partners, infants are tutored by their perceptual experiences to coordinate their attention in response to social cues and actions in order to communicate as well as to learn.

This transition does not happen all at once but rather gradually. It seems reasonable to hypothesize that for very young infants' attention is captured by the most salient stimulus in the visual environment, which is typically a face, and they continue to focus on that same stimulus until a new salient stimulus appears, or they habituate and then orient elsewhere. By contrast, the first signs of volitional attention appear around 3–4 months of age, when infants begin to display prospective control of saccades (Johnson, 2011). Once intentional control of visual attention emerges, infants' processing of contextual information begins to influence where they choose to attend. This contextual information will include social cues (e.g., gaze following, pointing) and goal-directed actions, which infants are beginning to learn about by 5–6 months of age (Rohlfing et al., 2012; Woodward, 1998). Although infants reveal some precocious understanding of these behaviors at early ages, we suggest that there is an important distinction between infants developing some representation of a person's goals or intentions, and responding to those perceived goals or intentions in a meaningful way (cf. Klin, Jones, Schultz, & Volkmar, 2003). In our study, it is not until sometime between 8 and 12 months of age that infants are prepared to modulate their attention in response to the actor's social cues.

2.5.3 Reciprocity Between Coordination of Attention and Social Understanding

Some theorists assume that the development of joint attention relies primarily on the development of social–cognitive knowledge, which enables infants to appreciate the intentions of others (e.g., Carpenter et al., 1998; Woodward, 2009). Unless one assumes that this social–cognitive knowledge is encapsulated as an innate module, it is necessary to explain how this knowledge is learned. Infants' visual attention biases them to look at people and their actions, and these results suggest that their attention becomes better coordinated with the actions of a social partner over time. These changes in the coordination of attention occur during the same period of time that infants begin to develop an understanding of others' intentions, which thus blurs the direction of effects. This is not necessarily an unwelcome conclusion, because it is quite conceivable that the development of joint attention represents a dynamic and reciprocal relation between the development of infants' social–cognitive knowledge and their attentional foraging of social interactions.

As such, the distribution of attention by the 8-month-old infants may have represented a phase where they were simply not yet aware of the social cues, and thus their responses did not differ as a function of these cues. This interpretation is, however, not likely to be entirely correct given what we know about infants' understanding of social cues (e.g., Bertenthal et al., 2014; Hood et al., 1998). Alternatively, these infants were still *learning* how best to distribute their attention during these bouts of joint attention with a social partner in which they were communicating face-to-face as well as jointly viewing one or more objects. During this learning phase, 8-month-old infants would have the opportunity to learn more about the social–communicative actions of others by mirroring them and observing their partner's responses (Bertenthal & Longo, 2008; Shepherd & Cappuccio, 2012; Woodward & Gerson, 2014). By contrast, 12-month-old infants were already able to represent the very basic intentions of the actors (e.g., Tomasello, 2008), and thus were no longer just exploring how to coordinate their attention with that of the actors. The function of attention for these older infants was more akin to a *decision* process in which their goal was to select the relevant information in order to decide where to look next.

2.6 Summary and Future Directions

2.6.1 Challenges to Studying Social Attention

Social attention does not develop all at once, but infants make rapid progress during their first year. We now know a good deal about what infants attend to, but our understanding of how this attention develops is still piecemeal and fragmentary. Early on, neonates show preferences for very simple face-like stimuli, or at least featural relations correlated with faces. Johnson and Morton (1991) suggest that these early stimulus-driven preferences predispose infants to learn quickly about the identification and discrimination of faces. Theorists who advocate for associative learning might predict that the frequency and duration of exposure to faces is responsible for what is learned, but experience per se is not sufficient for explaining the sequence or rate of learning. The "devil is in the details," which as of now are still very murky. For example, it is clear that the processes available for face perception improve with a shift from subcortical to cortical processing around 2 months of age (Johnson, 2011), and that the hedonic value of faces reinforces infants to continue looking at these stimuli (Triesch et al., 2006). Although we also know that infants begin categorizing faces by 3 months of age (Quinn, 2002), the specific learning mechanisms responsible for these accomplishments, or for the perceptual narrowing of the face schema to the same species (Pascalis et al., 2002), remain elusive.

One of the biggest challenges to identifying the processes responsible for the development of social attention is that it is a moving target and these processes continue to change with age and experience. If we focus on just the first few months of development, this question becomes at least a little more tractable, because it is assumed that attention is primarily, if not exclusively, driven by the stimulus, and thus predicting where infants will look is mostly a function of determining the salience of the stimulus. Yet, even this issue is difficult to resolve, because it remains controversial as to whether salience should be defined in terms of physical conspicuity, biological survival value, social meaning, or affective resonance (Gottlieb & Balan, 2010). Once infants begin to control the direction of their orienting through endogenous processes (i.e., goal-driven attention), the complexity of the problem explodes, because infants are then able to decide where to look next based on not only the salience of the stimulus but also their intrinsic or extrinsic goals, which are shaped by their social understanding and prior experiences.

In this chapter, we have focused on the development of joint attention to illustrate how stimulus salience, action understanding, and contextual modulation of attention contribute to its development. Each of these processes will be discussed in turn.

2.6.2 Stimulus Salience

As we discussed, infants begin to match or coordinate their attention to that of a social partner by 3–4 months of age when following eye gaze or the direction of a pointing gesture. It is possible for infants to accomplish this act without any understanding of the others' goals or intentions. In essence, infants learn to shift their attention in response to a deictic cue, which occurs because it is associated with movement in the same direction as the target (Rohlfing et al., 2012). The association with movement facilitates this shift because infants are capable of tracking objects by this age (Kellman & Arterberry, 1998), which will bias them to continue looking in the same direction. Presumably, the targets of these social cues are often rewarding and thus through contingency learning, or more formally, reinforcement learning (Triesch et al., 2006), they learn to shift their attention toward new objects or events.

As an aside, most of the evidence supporting this development is based on a spatial cueing paradigm, yet paradoxically this paradigm may not be well designed for studying social attention (cf. Birmingham & Kingstone, 2009). Recall that none of the gaze-cueing studies compared infants' responses to social and nonsocial cues, and the one study testing point following that compared these cues did not report an advantage for social over nonsocial pointing until 6 months of age. Although this failure might have been attributable to limitations in perceptual discrimination at 4 months of age, the evidence for a significant preference to the pointing hand versus the foil refutes this possibility. Instead, we suggest that the problem lies with the paradigm, because it tends to measure stimuli on a dimension in which the stimulus cues all share considerable similarity (i.e., communicating a specific direction; Gibson & Kingstone, 2006).

In the natural visual environment, it is first necessary to scan the visual array and select a stimulus cue, such as a face or eyes, before shifting attention in the direction of that cue. Some recent research suggests that it is during the selection phase that a social stimulus exerts its greatest advantage (Birmingham & Kingstone, 2009). If the stimulus cue is preselected as occurs in a spatial cueing paradigm, then the likelihood of observing a difference between processing social and nonsocial cues is reduced. Conceivably, this is the reason that so many adult spatial cueing studies fail to show a response time difference between gaze and arrow cues (e.g, Hommel, Pratt, Colzato, and Godijn, 2001; Kuhn & Kingstone, 2009; Tipples, 2002). Similarly, this paradigm is likely to underestimate differences in orienting to social and nonsocial stimuli in infants if these differences are partly attributable to selective attention. Indeed, this is very likely given that infants showed a strong preference for the pointing hand over the pseudo-hand and the arrow (Bertenthal et al., 2014). There is also evidence from brain studies that infants are biased to selectively attend to social stimuli, because specialized areas in the brain sensitive to these stimuli are already functional by 4 months of age (Grossman & Farroni, 2009; Johnson, 2011). If infants were tested in more naturalistic situations, we predict that the observed differences in responding to social and nonsocial stimuli would have been greater, because these differences would have been amplified by the greater likelihood of selectively attending to the social versus nonsocial stimuli.

2.6.3 Action Understanding

Once infants begin following the social cues of their partners, they have the opportunity for extensive practice and tutelage from observation. By observing others' orienting behaviors that they themselves are capable of performing, it is conceivable that infants will begin matching their own actions to those observed, and this will facilitate their understanding of the goals or intentions of the social partner. It is important to emphasize that this is a very gradual process, and seems at least somewhat dependent on motor experience. This is the reason that infants may engage in point following by 4 months of age, but do not demonstrate that they understand the others' intention in pointing until close to a year of age, after they themselves are capable of pointing (e.g., Brune & Woodward, 2007). Throughout the day during play and feeding with their caregivers, infants will have the opportunity to observe and mimic not only deictic cues but also other goal-directed actions, such as reaching and manipulating objects. By mirroring these actions (i.e., mapping observed actions to motor representations), infants will learn about the goals and intentions of actions performed in their field of view.

Although infants will have the opportunity to observe goal-directed actions from birth, it is not until 5–6 months of age that they begin to understand the relation between the action and the goal. There is now some very convincing research showing that this action understanding is related to motor experience (Woodward & Gerson, 2014), but there seems to be a tendency to dismiss observational learning too easily because of a failure to recognize the importance of social communicative cues and contingent feedback during these interactions. As we emphasized throughout this review, there is a reciprocal relation between social understanding and social attention, and it is therefore critical to consider the contributions of both when studying social cognition. More generally, it is rarely the case that two behaviors that develop, such as social attention and social understanding, will follow a sequential developmental sequence, because development is dynamic and nonlinear, and thus virtually all related behaviors interact as they change and become more complex (Thelen & Smith, 2008).

2.6.4 Contextual Modulation

Endogenous orienting of attention is akin to decision-making (Gottlieb & Balan, 2010), because the observer needs to process the current perceptual information and decide where to direct attention next. During joint attention, infants are expected to follow the gaze or pointing direction of their partner because they have learned that this response is often rewarding (e.g., Triesch et al., 2006). In most natural situations, however, the decision as to where to look next is not as straightforward. Infants observe multiple cues including not only gaze and pointing, but also facial expression, speech, prosody, body orientation, manual actions, etc. All of these cues are potentially informative and are selected based on prior knowledge as well as current goals (Boyer et al., 2015). If all of these cues predict the same response, then the outcome is clear, but this is rarely the case. As we discussed in the preceding section, the likelihood of infants responding to the actor's face or goal-directed actions is probabilistic and depends on how attention is modulated by other cues, such as head orientation and eye gaze or the manual actions that are performed. One important implication from this evidence is that it is not sufficient to record where an infant looks, because the reason for looking in a specific direction is often a function of the child's social understanding, which encompasses not only the current focus of attention but also contextual information including social communicative cues as well as goal-directed actions.

When do infants begin to modulate their attention in response to contextual cues? The findings from Boyer et al. (2015) suggest some responsiveness to manual actions by 8 months of age, but it was not until 12 months that infants showed systematic responses to multiple cues including direction of eye gaze. At first blush, this latter finding may seem at odds with the evidence suggesting the existence of gaze following by 3–4 months of age. Yet, the situations are very different, because gaze following at these young ages was observed only when the stimulus information was limited to eye gaze, and even this cue was subsequently removed in order to ensure that infants would shift their attention to the target. By contrast, infants viewing movies of actors engaged in joint attention with them as well as objects were confronted with a much more complex task that would be responded to differently depending on their social understanding. As we previously discussed, this social understanding was tutored by infants mirroring the behaviors performed by their caregivers, as well as being mimicked by them (e.g., Boyer et al., 2015; Bigelow & Power, 2014). This exploratory stage of joint attention also enabled them to begin identifying correlations between different cues so that eventually their direction of attention was not only a function of the salience or meaningfulness of specific AOIs (i.e., face, hands, objects) but also a function of informative contextual cues (e.g., eye gaze, goal-directed actions, facial expressions). Thus far, the research by Boyer et al. (2015) is restricted to measuring only one contextual cue at a time, but ongoing work is using information theoretic measures, such as Shannon entropy and cross-recurrence plots, to assess the predictability of the response from multiple cues simultaneously.

2.6.5 Conclusions

In this chapter, we have focused on social attention as a dynamic process that involves the responses of observers to actions (eye gaze, facial expressions, head and body orientation, goal-directed actions) performed by others. We have emphasized that social attention is not a monolithic process, and that it develops gradually throughout the first year in association with perceptual development, action understanding, and coordination of joint actions. Our primary goal was to show that social attention is not merely a product of development, but it is a process as well.

In essence, social attention is recast from the role of primarily informing researchers about where and how long infants look at social cues to how they are looking and how their attention will directly contribute to social learning. As infants' motor repertoire develops and they are better able to direct their attention to informative social cues, their understanding of others' actions continues to develop. This is the reason that there is a mutual and reciprocal relation between social attention and social understanding. The development of this relation is complex and involves the interaction of multiple factors, some of which were discussed in this chapter. An important goal for the future is to continue to explore how social attention is both a measure of social cognition and a mediator of its development.

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Chapter 3
Development of Brain Mechanisms for Social Attention in Humans

Vincent Reid and Kirsty Dunn

The capacity of an infant to detect and process human communication is an aspect of early development that has garnered much attention. A closer look at social-cognitive abilities in the first postnatal year reveals that eye gaze plays an essential role. This chapter seeks to outline how eye gaze detection and interpretation of gaze by infants during early development is a key aspect of social capacities. For example, as another person's eye gaze indicates the focus of their attention, prior work has shown that eye gaze guides learning about objects by 4 months of age (Reid, Striano, Kaufman, & Johnson, 2004; Reid & Striano, 2005). It has even been suggested that not only does mutual gaze establish the first social interactions, it also may be a key driving force behind infants' proclivity to attend toward human faces rather than other forms of stimuli (Gliga & Csibra, 2007). Given that such strong claims have been made with respect to the importance of gaze processing and later joint attention behaviors, this chapter seeks to review this body of literature. Starting with a brief overview of gaze and dyadic information-processing research, this chapter has a main focus on studies related to joint attention and more complex uses of gaze in social situations. As such research has recently been utilized in understanding the ontogeny of autism, we examine recent studies in this domain and investigate the possibilities for early screening for autism using social information and electroencephalography (EEG). Finally, we look to explore the potential of new techniques and theories related to EEG and how they will help to resolve open questions in our understanding of early social development.

One key issue is how neuroscience techniques have illuminated the development of these capacities. This chapter focuses on EEG-derived analyses as such methods

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have played a key role in our understanding of early social development over the past decade. It is, therefore, important to initially understand the strengths and limitations of such techniques before outlining why we have a firm understanding of social capacities related to gaze processing during early development.

3.1 Event-Related Potentials in Infancy

Data derived from behavioral measures such as those used by Farroni, Csibra, Simion and Johnson (2002), of which more will be outlined later, provide a rich source of information on what infants can discriminate, categorize, and learn. It is, however, important for the field of infancy for additional work to be conducted on how infants process visual information. One such category of information is the investigation of infant brain function. Electrophysiological measurements of brain activity are particularly well adapted to work with infants. EEG techniques and event-related brain potentials (ERPs) rely on the noninvasive and painless recording of brain electrical activity measured by electrodes placed on the scalp. An ERP can be defined as the resultant electrophysiological response derived from the onset of a specific stimulus or to the execution of a specific action (Stets, Stahl, & Reid, 2012).

The primary advantage of ERP research over other forms of brain-based methodology is that it provides excellent temporal resolution for viewing elicited processing, even to the tune of milliseconds. Conversely, spatial resolution is extremely poor. Further, additional spatial smearing of EEG activity will always occur due to the resistive properties of the meninges, cerebrospinal fluid, skull, and scalp. Despite these drawbacks in terms of spatial resolution, there are also distinct advantages for the developmental researcher. One aspect of ERPs that makes them particularly attractive for research in early development is that they do not require an overt behavioral or verbal response in passive paradigms. They consequently permit the study of phenomena that may be difficult or impossible to investigate with behavioral measurements alone (see, e.g., Striano, Reid, & Hoehl, 2006). This is particularly useful with infants when behavioral methods appear to indicate no discrimination between stimuli sets. A detailed discussion of the functional specifics of key ERP components found across development is far beyond the scope of this chapter, but there are a number of useful reviews of this literature (e.g., de Haan, Johnson, & Halit, 2003; Nelson & Monk, 2001).

There are a number of important caveats related to ERP studies with infants. The average attrition rate for visually induced ERPs with an infant sample is approximately 50 % (DeBoer, Scott, & Nelson, 2007; Hoehl & Wahl, 2012; Stets et al., 2012). The majority of participants are lost as too few trials are collected per condition to warrant inclusion into the final dataset. Precisely why a particular infant fails to attend to the stimuli is a topic that requires further examination. It may be that temperamental characteristics are a defining between-subjects factor for included and excluded groups. Of concern for developmental psychologists is whether systematic differences between these groups exist and if those differences relate to key developmental factors. For example, Marshall, Reeb, and Fox (2009) asked caregivers to rate their 9-month-old infant for temperament. The group of infants rated as having a highly positive temperament were found to have a lower attrition rate (40.4 %) than the group rated as having a highly negative temperament (52.2 %). This has possible consequences for interpreting results due to bias in the remaining included sample.

Recent attempts have been made to modify methodologies in order to improve attrition with ERP studies. Stets and Reid (2011) found that there were order effects for the amount of amplitude for an ERP component contributed within a standard ERP paradigm. This implies that for some components, the first few trials may be all that is required to make an informed decision on differential processing between conditions. Studies using adult populations have shown characteristics of habituation over trials when analyzing the P3 or OR components. These components typically occur between 300 and 600 ms in adults and are thought to reflect the updating of the stimulus environment (Donchin & Coles, 1988). A reduction in amplitude of this component across repeated stimulus presentations in both active and passive tasks (Polich, 1989; Polich & McIsaac, 1994; Ravden & Polich, 1998) as well as enhanced rehabituation of the OR component (Sambeth, Maes, Quiroga, van Rijn, & Coenen, 2004) provides strong evidence of neural habituation across trials. The infant P3 component, with a smaller amplitude and longer latency of 500–900 ms, was also found to respond in a similar manner to a study designed not to induce habituation (McIsaac & Polich, 1992). Therefore the development of the habituation behavior of this component cannot be concluded. A critical component of the infant ERP that is of key interest in relation to the topic of this chapter is the mid-latency negative component, or Nc. The Nc occurs approximately 300–700 ms after stimulus onset, is most prominent at frontocentral electrodes, and is thought to relate to the development of memory processes during the first 12 postnatal months. The Nc (see Fig. 3.1) is also thought to reflect attentional orienting to salient stimuli (Courchesne, Ganz, & Norcia, 1981) and/or a general attentional arousal (Richards, 2003), as it is larger to infrequent than frequent stimuli (e.g., Courchesne et al., 1981) and is larger during periods of sustained attention as defined by heart rate (Richards, 2003). Nikkel and Karrer (1994) found 6-month-olds showed generally reduced amplitude across trials for the Nc component in response to repeated visual stimuli in different blocks, indicating a reduction in attention to stimuli over time. Further work is required to determine which precise components in an infant ERP display these characteristics, though preliminary results suggest that this would be appropriate for visual studies. Potentially only 3–5 trials are required for some studies dependent on the component of interest. This would allow the inclusion of almost all tested participants.

The typical process of obtaining an ERP requires recording the EEG with indexed points in time, known as “triggers” or “time stamps,” around which segmentation of the EEG occurs. An epoch is extracted from the EEG that constitutes a baseline before the stimulus and a poststimulus period of an indeterminate length, dependent on the specific experimental paradigm. During data collection, the amplifier

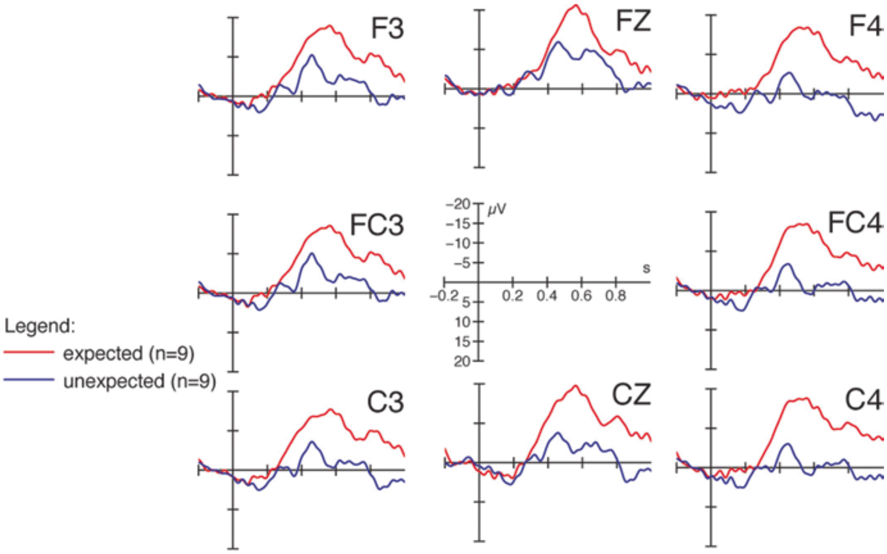

Fig. 3.1 *An example infant ERP, depicting a typical Nc component derived from visual stimuli.* Data depicted are a subsample of 7-month-old infants derived from Reid et al. (2009). The Nc is clearly seen as a large negative deflection on all frontocentral scalp electrodes across both hemispheres, peaking between 400 and 600 ms after stimulus onset. Note that negative is plotted upwards and stimulus delivery occurs at time zero

augments the obtained biological signals differentially, with every channel measured relative to a reference electrode. The difference between the two electrodes is then amplified, thereby providing a voltage measure for each channel that is relative rather than absolute in nature. The recording reference electrode is often located at the vertex electrode, which is located equidistant between the ears, at the top most part of the head. The reason for using this location for the recording reference is that it is close to other recording sites and it can be affected by ambient noise in a similar manner to the other channels. As EEG data are always relative—in the sense that the resulting data are a comparison between one electrode and another—data are often referenced after data collection to an electrode that is considered to be more suitable for reasons such as reliability and replication. Common final reference locations include the linked mastoids (behind the ears) or the average reference of all electrodes. As exogenous noise is a problem that is frequently encountered during the acquisition of EEG, after data collection the offline data are usually subjected to high-pass and low-pass software filters. High-pass filters can alleviate problems with slow wave drifts throughout data acquisition. Low-pass filters can remove high-frequency noise derived most typically from nearby electrical devices. Common bandpass examples are 0.1–35 or 0.3–20 Hz.

Once filtering has taken place, data are then typically edited, such that artifacts are removed. With adult data, this is most often performed by a simple algorithm, with parameters set to detect eye blinks, eye movement, and muscle artifacts. With infants, data are typically edited trial by trial in order to ensure that only valid trials are included, with the infant attending to the stimuli. Such comparisons require a video system that is synchronized to the EEG, and some EEG systems can embed the video signal within the EEG file. The removal of trials with artifacts can be performed at the same time. The remaining individual EEG segments are then averaged together to create one ERP for each condition. It is at this stage that assessment of the ERP can be made. Once the data have been collected from all participants, a grand average is performed where the individual averages of the participants are merged together to form an average of the overall effects.

3.2 Dyadic Gaze Processing

There is substantial evidence to indicate that sensitivity to eye gaze is present from birth, with ERP evidence from 4 months (Farroni et al., 2002, Farroni, Johnson, & Csibra, 2004). Neonates discriminate between direct and averted gaze, preferring to look to direct than averted eye gaze. In adults, the N170 component has been found to be specifically sensitive to human faces peaking around 140–170 ms after stimulus onset. The latency of the N170 in adults is shorter with larger amplitude in response to human upright faces (Bentin, Allison, Puce, Perez, & McGarthy, 1996). In infants, the N170 component is of similar morphology in that it is the first negative deflection after the P1 component over posterior locations. It also shows similar processing sensitivities such as larger amplitude in response to human upright faces (deHaan, Pascalis, & Johnson, 2002). Further, it peaks later than the adult component at around 240 ms and shows smaller amplitude (deHaan et al., 2002). By at least 4 months of age, discrimination of gaze direction is reflected in the N170 component of the visual evoked response to human faces, which has a higher amplitude for direct than averted gaze (Farroni et al., 2002). In a visual preference paradigm, Farroni and colleagues investigated human sensitivity to direct eye contact from birth. They presented 17 infants within 5 days of birth with pairs of faces. One face depicted direct eye contact while the other showed averted eye gaze. Infants looked longer and oriented more toward faces with direct than averted eye gaze, indicating a visual preference for direct eye contact. In a further study, 154-month-old infants were presented with the same stimuli sequentially in random order and ERPs were assessed. Eighty percent of infants showed a significantly larger negative “infant N170” response to direct than averted eye gaze, indicating a specific neuronal response to direct eye gaze. No difference was found between hemispheres in contrast to adult data, which suggest a larger response in the right hemisphere, despite its bilateral position (Bentin et al., 1996; DeHaan et al., 2002). Further, a later P400 component was found in response to direct eye gaze previously found to be sensitive to faces over objects (deHaan & Nelson, 1999). This component (exhibited around 450 − 390 ms) is thought to be a precursor to the adult N170 as, like the adult component, the infant P400 exhibits a faster latency in response to faces than objects (deHaan & Nelson, 1999) and is sensitive to face inversion by

3 months (deHaan et al., 2002; Halit, de Haan, & Johnson, 2003). Unlike the adult N170, this response to inversion is not yet specific to human faces. This study therefore showed preferential attention to direct eye gaze from birth and enhanced face processing from early infancy. The authors concluded that the processing of direct eye gaze is a major foundation for the later development of social skills. For this reason, it may be of little surprise that sensitivity for direct eye gaze can be found in early development. This bears a marked contrast to the N170 component in adult data. Puce, Smith, and Allison (2000) showed adult N170 actually shows a larger amplitude at a shorter latency in response to averted gaze than direct gaze. This has implications for the likely function of the N170 response during development, suggesting that it is sensitive to different facets of the environment at different points in development

Likewise, infants extract meaning from the direction of adults' eye gaze. The positive slow wave (PSW) component appears approximately 800 ms after the stimulus, has been previously related to context updating in infants (Nelson, 1994), and is detectable by around 3 months of age (Pascalis, de Haan, Nelson, & Schonen, 1998). Four-month-olds' ERP responses to happy, neutral, and angry faces with a direct or an averted gaze showed an increased PSW in the angry direct gaze condition only when compared with an averted gaze condition. This suggests that infants produce a novelty response to a face when an angry emotion is directed at them (Striano, Kopp, Grossmann, & Reid, 2006). No differences between direct and averted gaze in the PSW for the happy or neutral emotional stimuli were found. Adult samples also show a differential neural response to emotionally arousing stimuli reflected in the late positive potential (LLP) exhibited at around 350–400 ms (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). Schupp, Öhman, Junghöfer, Weike, Stockburger, and Hamm (2004) found an increased LLP response for threatening faces that were direct than averted eye gaze bearing a similarity to infant neural response. From an evolutionary standpoint, infant reaction to angry expression over other emotional expressions is logical. An infant should have a stronger reaction to an expression that may indicate a threat. From a social-cognitive point of view, this study indicates the sensitivity of young infants to information that is conveyed via the face. Importantly, this study convincingly showed that emotional processing is encapsulated within the context of gaze information. Further, this is manifested via ERPs within the PSW, thereby indicating novelty. Such a conclusion is reasonable given the unusual nature of angry faces in dyadic contexts for infants at 4 months of age.

These studies indicate that infants do not just simply show a special interest in faces from birth. They are able to visually discriminate between subtle features of the face, preferring direct to averted eye gaze and showing differential neural responses to different emotional expressions. Neural measurements have facilitated our understanding of facial processing during development. Through the assessment of the infant N170, we have been able to index cognitive performance that contains some similarities to that seen by adults, particularly with a broadly similar morphology and a sensitivity to human upright faces. Such relatively direct comparisons between ages would be impossible without recourse to EEG measures. The fact that specific neural correlates have been linked to dyadic processes is in itself highly illuminating. Prior literature on the cognitive properties of the infant N170 and the PSW allow for inferences to be made with respect to specific cognitive processes that would not be possible were we to rely on behavioral measures alone. In short, it is entirely reasonable to state that ERP responses have shown that infants develop face-processing capacities to an advanced stage in a manner that could not be understood were we to rely on behavioral measures.

3.3 Brain Processes Associated with Joint Attention

The Nc component of the infant's evoked response to an object is also of greater amplitude in joint attention contexts than when the infant views the object with no preceding joint attention interaction (Striano et al., 2006). Experimenters presented 9-month-old infants with randomized joint attention and non-joint attention trials (Fig. 3.2). In the joint attention trials, the experimenter gazed at the infant's face and then to a computer screen that displayed an object. In the non-joint attention trials, the experimenter only looked to the screen. Behavioral measurement showed a trend for infants to look longer to objects in the joint attention trials than the non-joint attention trials, although this difference was not statistically significant. ERP measurements in response to viewing the objects showed a significantly greater negative Nc response to the joint attention trials in electrodes overlying the frontal and central scalp. This was not found to the same extent for the non-joint attention condition. This shows that infants' attention to objects in their environment is facilitated and enhanced by social interaction. It also shows that infants are sensitive to the relationships between other people and objects in the environment, which may be a precursor to action perception. Social cues other than gaze have been shown, behaviorally, to contribute to the development of action perception. A number of studies show that 12- to 18-month-old infants' preferences for looking at objects and acting on objects are influenced by adults' affective responses to those objects. Infants were more likely to show a visual preference for an object that 5 minutes previously had been looked toward, when contrasted with a condition where gaze was directed away from the object. Infants were also less likely to perform an action with the object after an adult displayed a negative expression following this action and less likely to perform an action with an object in the presence of a third party who had previously expressed a negative expression in response to another's interaction with an object (Repacholi, 2009; Repacholi & Meltzoff, 2007; Flom & Johnson, 2011). The neural correlates of infants' responses to adult affective action cues are open for investigation.

Research with ERPs has shown infants are sensitive to components of joint attention, such as mutual eye contact, from an early age (Farroni et al., 2002), as discussed earlier. Parise, Reid, Stets, and Striano (2008) aimed to further this research by investigating the relationship between these findings and the results of behavioral studies of mutual co-orientation toward an object in older infants. As be-

Fig. 3.2 *The experimental paradigm reported in Striano et al. (*2006*). Leftmost* column depicts the experimenter and *rightmost* column the infant. The *top* two rows depict a face-to-face interaction where the experimenter and infant look at one another. In the second *top* row they share joint gaze toward the screen, where objects were displayed. The second row from the *bottom* depicts the infant looking to the experimenter, but not encountering a direct gaze. The *bottom* row depicts what happens next with the infant then fixating to the screen where objects were shown (with the experimenter's gaze remaining on the screen)

havioral measures cannot be used in younger infants, due to the absence of overtly manifested co-orientation behaviors, ERPs were used in order to overcome this barrier and to measure the effect of joint attention much earlier, in 5-month-old infants. During a familiarization phase, infants were presented with three different objects on a screen. An experimenter was present next to the display and alternated her head between the object and the infant, drawing attention with vocalizations, such as “look at the colors.” In a between-subjects design, the experimenter engaged in mutual eye contact for those in the joint attention group and looked to the chest of those in the no joint attention group. The experimenter then left the room and the test phase began. The objects were presented to the infants again and ERP responses were measured. Infants showed a significantly more negative Nc component in the joint attention group than those in the no joint attention group. This indicated that a social interaction featuring mutual eye gaze prior to object presentation influenced the level of attention that infants subsequently allocated toward the objects. This is in contrast to Striano et al. (2006) where eye gaze was present during the object presentation. Further, this influence remained even when mutual eye gaze was not concurrent with the test trials. This study highlights the ability to assess the neural correlates of joint attention in infants when inducing behavioral responses during social interactions.

One study (Grossmann & Johnson, 2010) has examined aspects of joint attention utilizing near-infrared spectroscopy (NIRS). A number of recent reviews offer insights into this new technique for examining functional brain activity with infrared light emitted into the skull and then detected by sensitive probes (Gervain et al., 2011; Ferreri, Bigand, Perrey, & Bugaiska, 2014; Lloyd-Fox, Blasi, & Elwell, 2010). Data are modulated in a similar manner to functional magnetic resonance imaging (fMRI) in that changes in blood oxygen levels are monitored in relation to brain activity. NIRS measures both oxygenated and deoxygenated blood levels, though, in contrast to fMRI, which measures changes in oxygenated blood levels only (Lloyd-Fox et al., 2010). NIRS has a lower temporal resolution than EEG, a lower spatial resolution that fMRI, and data acquisition is restricted to the measurement of activity in the cerebral cortex with depth dependent upon the age of the infant and depth of the skull (Ferreri et al., 2014; Lloyd-Fox et al., 2010). Further, Fukui, Ajichi, and Okada (2003) showed NIRS penetrated deeper into white matter than gray matter, reflecting variations in the properties and interaction of NIRS within the brain. Despite this, NIRS offers many advantages to developmental researchers, offering better spatial information than EEG and better temporal information than fMRI as well as being inexpensive, portable, and less susceptible to movement artifacts than either measure (Lloyd-Fox et al., 2010). Therefore, NIRS offers a valuable tool for advancing our knowledge of developmental neuroscience. Grossmann and Johnson (2010) investigated 5-month-old infants’ capacity to detect ostensive cues and gaze toward an object. This was contrasted with two control conditions that assessed the ability to detect either gaze away from an object or no direct eye contact prior to gaze at an object. From 24 measured locations with dorsal, ventral, and lateral regions of interest, two probes near to left dorsal prefrontal regions showed differences between the ostensive gaze condition and the two control conditions. A minimum of four trials per condition were used as inclusion criteria. The authors concluded that there is an early neurobiological foundation for joint attention and that parts of the left prefrontal cortex are selectively activated in response to this. As is common in developmental research when new techniques are first employed, adequately universally accepted parameters for data collection and interpretation are lacking in the field of near-infrared, making it difficult to draw meaningful conclusions with respect to the validity of the results of the early studies. The work of Grossmann and Johnson (2010) rightfully belongs to this cohort of pioneering work.

Even though it is generally believed that joint attention has an impact on the development of cognitive capacities, there is little direct evidence of systematic links. Kopp and Lindenberger (2011) aimed to investigate the effects of joint attention on long-term memory in 9-month-old infants. Using a procedure similar to that of Parise et al. (2008), infants in the familiarization phase were presented with objects in either a low or high joint attention condition. In the high joint attention condition, an experimenter was present next to the display and alternated gaze between the objects and the infant engaging in eye contact, pointing to the toy, and using vocalizations, such as "what a beautiful toy." In the low joint attention group, the experimenter alternated gaze between the object and the infants, but directed eye gaze toward the chest of the infant. The experimenter did not point or use vocalizations and infant-directed speech was instead delivered through speakers. Following this, the experimenter left the room and the infants participated in two test sessions. The immediate recognition session followed immediately and a further delayed recognition session followed 7–11 days later. In these sessions, ERP response to the familiar as well as novel objects were measured. Overall, there was a larger Nc amplitude to novel objects and there was a shorter latency for response to familiar objects. Even though the Nc component showed no differences between joint attention groups, the authors believed that this was the result of the presentation of novel objects. Parise et al. (2008) only presented old objects from the familiarization phase. The presentation of novel objects in test trials of Kopp and Lindenberger (2011) may have overshadowed any joint attention effects on attention to the objects. Overall this indicated an increase in attention to novel over familiar objects.

Addressing the effect of joint attention on memory processes, the PSW component, related to memory updating (de Haan, 2007), was also analyzed in Kopp and Lindenberger (2011). A larger amplitude was found in response to familiar than novel objects in the immediate recognition session for those in the high joint attention group only. In addition, a Pb component was also detected. The Pb component is a positive amplitude component appearing around 200–400 ms after stimulus onset in central and anterior sites that is linked to stimulus expectancy (Karrer & Monti, 1995, Webb, Long, & Nelson, 2005). This manifested itself in Kopp and Lindenberger (2011) with a larger amplitude in response to familiar items in the delayed recognition session for those in the low joint attention condition. This study therefore showed differential effects of joint attention on long-term memory during immediate recognition tests (affecting PSW) compared with delayed recognition tests (affecting Pb). The authors concluded that joint attention affects long-term memory by enhancing the relevance of the attended objects. This study should be highlighted as it succeeds in showing a direct link between joint attention and cognitive development as a function of neural correlates.

3.4 Gaze Processing in the Context of Other Cues

How are eye gaze and triadic and joint attention processed in the context of other social cues? Even though eye gaze is a particular stimulus that is processed by specialized neurons in the primate cortex (Perrett, Hietanen, Oram, Benson, & Rolls, 1992), it is rarely processed in isolation from further information, such as head and body posture. How gaze interacts with the profile of the head was investigated by Farroni et al. (2004). They measured ERP responses to direct compared with averted eye gaze from upright and inverted heads in a sample of 4-month-old infants. In the first of two experiments, infants were shown faces oriented to 45° angles to the left or the right with either direct or averted eye gaze to the infant. Focusing on the putative infant N170, a significantly larger negative amplitude was found in response to faces with direct eye gaze, even when the head position itself was shown at an angle. Addressing alternative low-level explanations, such as face symmetry and spatial differences that occur between faces with direct and averted eye movements, a second study repeated procedures with upside down faces. There were no significant differences in infant N170 responses to eye gaze as a function of face inversion. When comparing these results to infant processing capacities as seen in Farroni et al. (2002), there was a significant interaction between experiment and gaze direction. This showed the upright face context is necessary for enhanced processing of faces through direct eye gaze. As symmetry and local spatial features are affected in the same way between direct and averted eye gaze in both upright and inverted heads, this cannot explain differences in upright heads. This study indicates a sophisticated gaze detection system by 4 months of age. Infants preferred direct eye gaze, even when the head is oriented away. The authors concluded these effects therefore cannot be explained through low-level factors. This suggests the information conveyed by eye gaze is attended to in preference to the social information relayed via head orientation. Recent research with adult samples using line-drawn faces, though, has shown no difference in N170 response to direct and averted eye gaze and authors suggested differences in neural response to eye gaze could be due to changes in contrasts between the iris and sclera (Rossi, Parada, Kolchinsky, & Puce, 2014).

Exploring the components of eye gaze in more detail, Farroni, Massaccesi, Pividori, and Johnson (2004) investigated the effects of the movement of the eyes versus the final gaze position in newborn infants. The authors first replicated the results of Farroni et al. (2002) using schematic faces under the assumption that the contrast would be more appropriate for newborn visual acuity. Infants looked longer to direct compared with averted eye gaze. In a subsequent study, infants were faster to orient to a target that was congruent to the eye gaze cue. Finally, the authors removed the movement component of an eye gaze cue so that only the final gaze position was shown and found no difference in saccadic reaction times when the cue was given in the presence of the target location. Infants were faster overall when movement was removed than in the previous study. When the cue was given before the presentation of the target, infants showed no significant differences in number and latency of saccades between congruent and incongruent cues. Due to variation in the number of trials participants contributed, the percentage of saccades in each condition was analyzed compared to chance. A larger percentage of saccades was found in the direction of the cued side. This showed that infants could follow the higher contrast part of the eye, even when the movement was not visible. In contrast, the pupil final position did not have an influence on the location of infant attention.

Individual aspects of joint attention cues have been investigated with respect to how they influence infants' processing of objects. Reid and Striano (2005) found a visual preference for non-cued over gaze-cued objects via looking preferences. Reid et al. (2004) found enhanced PSW for previously non-cued objects, indicating context updating is necessary for non-cued objects, presumably as they had not been processed during the initial gaze phase. This extra update could potentially explain longer looking times in behavioral measurements. Wahl, Michel, Pauen, and Hoehl (2013) aimed to investigate whether an inanimate object, showing the same movement and orientation as a human head, could affect infant object processing in a similar manner for 4-month-old infants. The authors replicated the object-processing paradigm of Reid and Striano (2005) utilizing eye-tracking techniques and ERP assessments. In the human head experiment, a human head was presented on a screen facing the infant in order to establish eye contact. A pair of colorful objects were then presented on either side of the head. The person then turned their head and eye gaze to the left or the right side, toward one of the objects and away from the other. Test trials then consisted of eye-tracking measurement in response to a visual preference test and ERP measurement in response to singularly presented objects. In a second experiment, the same procedure was followed with a second group of infants but the human head was replaced with a car. The car began trials with the front of the car facing toward the infant. This then rotated to face the left or the right toward one of the two objects that were presented on either side.

Results in Wahl et al. (2013) showed that those in the human head condition showed increased visual attention and increased amplitude for the Nc component in response to non-cued objects when contrasted with cued objects. Those in the car condition showed no significant visual preference and only a marginally significant difference in late PSW activity, associated with memory encoding. This indicates that non-cued objects are processed less efficiently leading to a novelty induced attentional bias toward these objects during test phases. The eye-tracking results were in accordance with those reported in a previous research as eye tracking demonstrated a visual preference for previously non-cued objects (replicating Reid & Striano, 2005). However, they did not find enhanced PSW for non-cued objects as was found by Reid et al. (2004). It is possible that when an infant sees both head and eye gaze movement (compared to just eye gaze as in the earlier study), this has a stronger impact on ERP responses. Another possibility is that the sample size of 12 in Reid et al. (2004) effectively underpowered the analyses in that study. A sample size nearer to 16 may have yielded different results. Overall, Wahl et al. (2013) show that human head orientation and gaze direction have a reliable effect on infants' object-directed attention. Inanimate objects, in contrast, have a limited effect on infants' object processing, indicating the importance of human agency in influencing infant object processing. It is possible that these effects may be enhanced in the presence of a real human compared with the human head displayed on a screen as in Reid et al. (2004).

There is now a strong evidence that indicates that eye gaze without a congruent head turn affects infants' object processing at 4 months of age (Reid & Striano, 2005), as well as eye gaze with a congruent head turn (Wahl et al., 2013). Hoehl, Wahl, and Pauen (2014) aimed to explore the separate effects of both eye gaze and head turn on infants' object processing. Infants of 4 months were assigned to either eye gaze or head turn conditions. Using stimuli similar to Wahl et al. (2013), infants were presented with a human head in the center of the screen facing forward. A pair of objects were then presented to each side of the head. In the eye gaze condition, the person then shifted their gaze to the left or the right while keeping their head stationary, facing toward the front. In the head turn condition, the eye gaze remained stationary, facing forward, while the head shifted to the left or the right. In test trials, eye tracking measured visual response to a pair of cued and non-cued objects and ERP measurement indexed neural response to singular objects that had been either cued or non-cued in random order. Eye-tracking results indicated significantly longer looking to previously non-cued objects with no difference between eye gaze and head turn conditions. Similarly, ERP results revealed increased Nc amplitude for previously non-cued objects when compared with cued objects with no difference between eye gaze and head turn conditions. Thus, the effects of Wahl et al. (2013) were replicated as infants showed a visual preference and increased attentional response to non-cued objects. Specifically, this study shows that both eye gaze and head turn, as components of joint attention, independently influence the direction of infant attention and processing of objects. Further, it is the movement of each component that is crucial to the influence of either component when the other is incongruent. Simple movement, though, cannot explain these results as the movement of an inanimate object has only limited influence on infant attention (Wahl et al., 2013) indicating it is *specifically* human eye and head movements that moderate infant attention. This could be the basis for later developments in social-cognitive processing as work with human adults has shown that the influence of head information is actually attenuated by incongruent eye gaze information (Langton, Watt, & Bruce, 2000) via eye-tracking data, whereas infants in this study did not show differences between the use of either component.

An awareness that gaze may facilitate the quality of social information may be linked to other forms of social development. Engaging the gaze of an adult while observing an unusual action at 20 months predicts theory of mind abilities at 44 months (Charman et al., 2000). This implies that there is a link between action understanding and theory of mind. Myowa-Yamakoshi, Kawakita, Okanda, and Takeshitab (2011) found that 12-month-olds who have experienced being blindfolded look longer at a blindfolded actor who succeeds at performing an action than one who fails, while never-blindfolded infants showed the opposite preference. Thus, imitated and joint actions may not only facilitate social processing in infancy, but may contribute to the development of other social-cognitive skills, such as perspective taking. Work by Mundy and colleagues (e.g., Mundy & Jarrold, 2010) also indicates that joint attention facilitates many distributed cognitive systems, including orientation of attention and regulation through to the development of symbolic processing.

In conclusion, sophisticated facial processing in infants during early development has a strong impact on other areas of cognitive development. A number of studies have shown that the use of gaze has a key influence on infants' learning from the environment. Information from others' eye gaze and head turns independently influences infant attention to objects and the subsequent processing of those objects. Though both sources of influence are important components of facial processing, the information of a moving component is preferentially processed over the information of static social information. Additionally, clear links have been made for the role of facial processing on the development of memory and other social-cognitive skills. It is due to the measurement of ERPs that we know infants have a much more sophisticated capacity to utilize social information to learn about the environment at an earlier age than would otherwise be possible were we to rely on behavioral measurements. Further, it has highlighted the importance of facial processing for the development of other cognitive capacities, such as memory.

3.5 Gaze and Joint Attention: Implications for Autism

The research outlined thus far in this chapter has implications for our understanding of autism. This is because the ability to detect aspects of human action, such as gaze cues, is often impaired in those diagnosed with autism (Baron-Cohen, Campbell, Karmiloff-Smith, Grant, & Walker, 1995; and see also Shultz et al., Chap. 7, this volume). Autism is characterized as a social-cognitive disorder, with many core deficits evident during social relations with others (see Frith, 2003, for a review). Thus, in order to map the parameters of autism, we first need to understand how these cognitive systems work in typically developing populations. No work has been conducted on how infant processing of gaze and head direction relates to adult brain activity in the same tasks. Frustratingly, no work has been conducted on how neural activity associated with gaze cues changes throughout early development, including toddlers and preschool-age children. This makes it difficult to relate these factors associated with early social cognition to atypical processing unless a certain amount of inference is made rather than utilizing direct comparisons.

More specifically, one of the deficits in the social domain is the inability to share enjoyment, interests, or achievements with other people through nonverbal behaviors. This deficit has been described by looking at aspects of social behavior, as for example joint attention skills and—at a more basic level—orienting to and following the eye gaze of another person. As this is an extensive topic, this chapter can only provide a rather limited insight on this complex matter (see Schulz, Jones, & Klin, Chap. 7; Bush & Kennedy, Chap. 8 this volume for a more extensive review of this literature).

Our understanding of the underlying deficits in ASD has been facilitated by neuroscience methods. It has been proposed that irrespective of developmental age, the initiation of joint attention relies on a dorsal "social brain" system, including the dorsal medial prefrontal cortex and anterior cingulate, while responding to joint attention is accomplished by a posterior attention system associated with gaze following and the flexible shifting of attention (Mundy, Card, & Fox, 2000; see Mundy, 2003 and Vaughan Van Hecke & Mundy, 2007 for extensive reviews).

Testing with direct and averted gaze stimuli in children with ASD has indicated that ERPs vary as a function of the condition. Grice, Halit, Farroni, Baron-Cohen, Bolton, and Johnson (2005) presented faces with direct or averted eye gaze to 3- to 7-year-old typically developing controls and an age-matched ASD group. In the ASD group, but not in the control group, a variant of the N170 component was increased for faces with direct relative to averted gaze. Grice et al. (2005) concluded that processing of eye gaze direction may be delayed in children with ASD, as a similar effect in response to direct gaze has been observed in infants (Farroni et al., 2002), but not in adults (Taylor, Edmonds, McCarthy, & Allison, 2001). Different results were obtained in a similar study that required active detection of specific gaze directions from participants. Senju, Tojo, Yaguchi, and Hasegawa (2005) found an increased posterior negativity (similar to but thought to develop later than the infant N170) during detection of direct gaze in typically developing children, but found no difference between direct and averted gaze for an ASD group with the same task. Both studies suggest differential neural processing of gaze direction in ASD. The divergence of the direction of this difference can likely be accounted for by methodological differences, namely an active oddball paradigm versus a passive viewing task, different recording systems, orientation of the facial stimuli, and chronological age of the participants. For example, Senju et al. (2005) investigated an older sample of children that may have developed a more sophisticated posterior negative component that responds to direct eye gaze in the way as the infant N170. The at-risk sample in this study might have delays in the development of this component yet the infant N170 component might have developed to the level of the younger typically developing children as seen in the study of Grice et al. (2005), resulting in no neuronal difference between conditions.

Difficulties with response to eye gaze have specifically been investigated as a potential predictor for autism in later life. Elsabbagh, Mercure, Hudry, Chandler, Pasco, and Charman (2012) conducted a longitudinal study of infants with and without familial risk of autism. At 6–10 months, infants' ERP responses to direct and averted eye gaze were measured, utilizing stimuli from Farroni et al. (2002). There was a significant interaction between risk group and condition for the P400 component. Those in the control group showed a differential ERP response to direct compared with averted eye gaze, whereas those in the at-risk group did not. This study indicated a difference in neural response between those with and without risk for autism in the absence of a difference in manifested behavior at that time point. Clinical research assessments were then made at 24 and 36 months. Those in the control group, along with those in the at-risk group who were not subsequently diagnosed with autism, had showed an increased amplitude of the P400 component to averted eye gaze when contrasted with the direct eye gaze in early infancy. No such difference was found in those who were diagnosed with autism in later life. This study indicates that a differential ERP response to direct compared with averted eye gaze at 6 months could be a predictor of autism diagnosis in later development.

A closer examination of the results in Elsabbagh et al. (2012) suggests that the overall effects that are reported in the study are likely driven by the difference in neural response between those in the control group and those with an early diagnosis of autism. Therefore, though promising, these results do not show that neural response to eye gaze is sufficient to be a predictor of later autism diagnosis for those with a later diagnosis. Stahl, Pickles, Elsabbagh, Johnson, and BASIS Team (2012) reported successful classification methods to determine, on the basis of ERP measurements reported by Elsabbagh et al. (2009) and Elsabbagh et al. (2012), whether infants were likely to belong to control or high-risk groups. This shows the first step for the use of ERP data in the early detection of autism. This is currently of limited use for, as Griffin and Westbury (2011) noted, only 5–10 % of infants in high-risk groups (infant siblings of a child with autism) actually go on to receive a diagnosis of autism later in development. Thus, high-risk groups involve the responses of around 90 % of infants in the sample who will not be subsequently diagnosed with autism. The authors concluded that it would be more useful to study how ERP measurements at the individual level, rather than the group level, distinguish between those in the high-risk category who do, and do not, go on to show behaviors associated with autism. Even though ERP responses to eye gaze have been shown to differentiate between typically developing and high-risk groups for autism, this is not yet specific enough to be an appropriate tool for early autism detection.

Taken together, the complexity of the topic calls for more studies comparing different stages of development and children with different mental abilities, using both behavioral and neuroscience methods. Further analysis of infant neuronal response to other components of social information processing could improve the prediction of diagnosis earlier in infancy. This will not suffice if the aim of research is to produce a potential screening tool for autism during early development. Multiple stimuli are needed for a robust screening device. This is at odds with ERP techniques, which rely on presenting relatively few stimuli many times in order to overcome small signal-to-noise ratios. Recently however, Stets, Burt, and Reid (2013) found that infants attend more to stimuli that feature variation, with almost all infants included in the final sample. This, coupled with work indicating that relatively few trials provide meaningful data (Stets & Reid, 2011), points to the possibility that a battery of stimuli sets could be utilized for the purposes of early screening, with the outcome that over 95 % of infants will provide enough data for a meaningful analysis. Recently, methods have been developed which analyze single trials in adult ERP studies using discriminant function analyses and machine learning methods (e.g., Bishop & Hardiman, 2010; Blankertz, Lemm, Treder, Haufe, & Mueller, 2010).

In short, technical challenges related to data acquisition have now been overcome. Importantly, the high feature dimensionality that ERP data create also poses challenges for predictive classification; however, these have also been overcome (Stahl et al., 2012). It is only a matter of time before reliable algorithms will be developed that predict later developmental outcomes as a function of deficits in social information processing, including gaze processing and joint attention. Such outcomes will include the likelihood or severity of autism for an individual child.

3.6 Promise of New Techniques and Paradigms

ERPs only represent one way via which EEG data can be interpreted and understood. Over the past 15 years, the investigation of event-related oscillations (EROs) has produced some potentially very important results within the field of infancy research (e.g., Csibra, Davis, Spratling, & Johnson, 2000). EROs are bursts of EEG that occur within, and across, specific frequency bands. In order to detect these oscillations, time–frequency analysis (the analysis of the time at which a value of a given frequency is present) of single trials is followed by the averaging of the summed power across trials. Prior to extolling the virtues of EROs, it should be noted that some important factors are not currently known in terms of how they behave with infant populations. For example, the number of trials needed for a reasonable signal-to-noise ratio is not known. The picture is also far from clear in terms of how frequency bands change across early development. The result is that it is difficult to make comparisons between different ages of infants.

For the purposes of this chapter, we will focus on EROs derived from the induced class of oscillations. These are produced with a different latency for each stimulus presentation. The induced oscillation therefore has a loose temporal relationship to the stimulus—it is not time-locked to the stimulus. When standard evoked response averaging techniques are applied to the dataset, the induced oscillation is effectively edited from the final data due to its variable temporal relationship with the stimulus. In order to detect these oscillations, time–frequency analysis of single trials is followed by the averaging of the summed power across trials. Induced oscillations will be detected provided that the signal-to-noise ratio is adequate—although there are no standards for this within the field and is likely driven by the strength of the eliciting stimulus. Further, detection will occur if the latency variation between and within trials does not exceed the duration of the wavelet that was utilized in the time–frequency decomposition (Csibra & Johnson, 2007).

Three areas of research have focused on EROs within the infancy domain. These include investigations of gamma (approximately 40 Hz) in relation to perceptual binding (e.g., Csibra, Davis, Spratling, & Johnson, 2000), where a unified percept is believed to be reflected in an increase in power within the gamma frequency. Mu, an alpha activity putatively driven by sensorimotor activity, has been investigated with respect to the mirroring system (e.g., Reid, Striano, & Iacoboni, 2011). Finally, frontal alpha activity (6–9 Hz in infants) has examined the role of EROs during recall and learning (e.g., Hoehl, Michel, Reid, Parise, & Striano, 2014).

One particular advantage of investigating time–frequency relations is that it is possible to investigate changes over time to the perception of dynamic stimuli, such as film clips, or when participants are involved in face-to-face or "live" interactions. One immediate advantage of such paradigms is that it allows for more realistic designs within studies. Rather than discussing social information processing as a consequence of an infant looking at a screen, it is now possible to have real interactions between individuals. This paves the way for the possibility of a plethora of studies, each of which could increase the complexity and ecological validity of social-cognitive tasks. Imagine, for example, the capacity to have two individuals engaging in direct eye contact. EEG could be acquired from each individual simultaneously and calibrated to ensure that the timing of events is synchronized (hyperscanning; see Montague et al., 2002). Pioneering studies of this nature have been carried out with adult samples whereby participants either follow the gaze of another or follow a color instruction to view a target object (Lachat, Hugeville, Lemaréchal, Conty, & George, 2012). With eye-tracking data included from each participant (see Fig. 3.3), many facets of social development could be investigated that are not currently within the bounds of current paradigms. For example, issues

Fig. 3.3 *An example of a direct eye contact condition between two adult participants during an experiment where two EEG systems have been linked with two eye trackers*. Eye-tracking information determines the location of the respective participant foveal fixations within the facial area of the social partner. Such techniques promise to provide much information for our understanding of attention in social interactions

such as to which of the two partners initiates joint activities can now be examined, together with how this affects neural correlates. Were we to find that substantive effects are due to the communicating/receiving roles within the interaction, this could rearrange our understanding of the primacy of the structures within joint attention.

Some movement within the field toward the direction of oscillations and live interaction has already taken place. Hoehl et al. (2014) examined the data obtained in the live ERP paradigm reported in Striano et al. (2006). Recent research into the cognitive properties of alpha in non-infant populations has indicated that it is involved in learning (Klimesch, 2012), joint attention (Lachat et al., 2012), and mirroring (Shepherd, Klein, Deaner, & Platt, 2009). Desynchronization, or a drop in power with a frequency band, was observed in the alpha band for the condition that initially featured direct eye contact. This effect was not seen in the condition featuring no direct eye contact, and cannot be explained by mirroring processes as the behaviors of each social partner are matched during the object presentation phase. Rather, it is possible that the alpha desynchronization observed in this study could reflect the infant being in a receptive state for knowledge transfer. Such an interpretation more closely aligns to concepts advanced by Klimesch (2012), whereby access to semantic knowledge occurs during learning. The ostensive cue of direct gaze may have induced the infant to prepare for information that is socially directed at them. For a review of relevant action-related research, see Ni Choisdealbha and Reid (2014).

Much is unknown during social interactions that could be resolved via the assessment of EROs. For example, it is known that temporal region gamma frequency occurs during object maintenance paradigms (e.g., Kaufman, Csibra, & Johnson, 2005). Are such systems operational during joint attention, in order to view objects from the perspective of another person? There is certainly evidence that increased gamma activity is related to processing direct eye contract when contrasted to averted eyes. Grossmann, Johnson, Farroni, and Csibra (2007) found an increase in right prefrontal gamma for direct gaze when reanalyzing data from 12 infants that were originally reported in the ERP study conducted by Farroni, Csibra, Simion, and Johnson (2002). Importantly, do other ostensive cues, such as uttering an infant's name, also induce alpha desynchronization in a social situation? What is beyond doubt is that ERO paradigms will be the basis of much of the next cohort of studies investigating social processes during early development.

3.7 Looking Forward and Concluding Remarks

The ability to process dyadic information is evident from birth with triadic capacities developing to a sophisticated level early in postnatal development. Poor capacity for joint attention at older ages can be indicative of developmental disorders, particularly autism. This area of research would benefit from concerted links between the cross-sectional research that has been conducted and the later effects of poor joint attention on development. Longitudinal research would allow for a genuinely developmental context for related cognitive functions. This would show the developmental links between early joint attention behaviors and more complex triadic interactions found later in toddlerhood, such as the initiation of, rather than response to, joint attention and declarative pointing. Further, the links between the dyadic and triadic behaviors are not yet clear despite this having important consequences for our understanding of development. For example, the ability to mutually attend to objects is important for language learning (Brooks & Meltzoff, 2005). Earlier transitions from dyadic competencies to triadic behaviors could be related to more advanced language learning occurring earlier in development.

Longitudinal studies would also improve our understanding of the effects of joint attention on the measurement of other developing cognitive processes. The ability to participate in joint attention has been shown to actually mask the level of other areas of development. Topál, Gergely, Miklósi, Erdőhegyi, and Csibra, (2008) showed how social communication in the context of object learning could have caused 10-month-old infants to encode semantic, general information, rather than episodic information. This in turn reduced search performance when an object was hidden within their paradigm as episodic information was required for the knowledge of the object's location. Longitudinal research could highlight key ages at which infants begin to interpret and possibly misinterpret the function of joint attention contexts. This could also benefit research measuring infant behavior in respect to other cognitive processes, thereby avoiding the underestimation of infant cognitive capacities in general.

The emerging field of hyperscanning is likely to play a large role in providing key information on developing brain function related to social information processing. Brain-to-brain coupling, where both brains are assessed simultaneously during an interaction, stands to fundamentally alter the scope of social-cognitive research utilizing neuroscience measures. The standard use of static stimuli does make timing of events highly precise; however, this is at the cost of ecological validity. Further, it may potentially mask actual processes that occur during social interactions. For example, it is known that infants are highly sensitive to the temporal contingency of interactions (Striano, Henning, & Stahl, 2005). This sensitivity may be crucial to infant learning mechanisms (Kuhl, 2007). Hyperscanning methods will allow for a far more nuanced and accurate picture of developmental aspects of social cognition, not least when applied in conjunction with ERO techniques. In our view, this approach is likely to yield more information on the neural basis of social abilities when contrasted with pursuits utilizing other neuroscience measures. NIRS, for instance, could tell us crucial information about the neural basis of social development. Unfortunately, those brain areas such as the anterior cingulate that appear to be crucial to attention mechanisms, as determined by EEG source analysis (Reynolds & Richards, 2005), are not capable of being indexed by NIRS. Until such time as the quality of NIRS methods improves within the field, it is likely that EEG and EEG-derived methods will remain the dominant tools in early social-cognitive research.

It is likely that future advances in the area of social attention during infancy will incorporate more sophisticated models of brain activity. The field is still at a stage where terms for neural mechanisms and cognitive systems are often used interchangeably. Of course, specific brain regions cannot be determined from EEG measures. It is perhaps for this reason that proposed neural systems suggested yet are only cautiously cited in subsequent studies in the field. Nonetheless, a degree of precision derived from converging evidence across multiple studies will certainly facilitate our understanding of how attention is involved in social information processing during development.

In the future, novel techniques of measuring infant cognitive capacities, such as EROs, will facilitate our understanding of the development of joint attention. It will also allow us to place joint attention behaviors in a truly developmental context.

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Chapter 4
Neural Bases for Social Attention in Healthy Humans

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In this chapter we focus on the neural processes that occur in the mature healthy human brain in response to evaluating another's social attention. We first examine the brain's sensitivity to gaze direction of others, social attention (as typically indicated by gaze contact), and joint attention. Brain regions such as the superior temporal sulcus (STS), the amygdala and the fusiform gyrus have been previous-

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ly demonstrated to be sensitive to gaze changes, most frequently with functional magnetic resonance imaging (fMRI). Neurophysiological investigations, using electroencephalography (EEG) and magnetoencephalography (MEG) have identified event-related potentials (ERPs) such as the N170 that are sensitive to changes in gaze direction and head direction. We advance a putative model that explains findings relating to the neurophysiology of social attention, based mainly on our studies. This model proposes two brain modes of social information processing—a nonsocial “Default” mode and a social mode that we have named “Socially Aware”. In *Default mode*, there is an internal focus on executing actions to achieve our goals, as evident in studies in which passive viewing or tasks involving nonsocial judgments have been used. In contrast, *Socially Aware mode* is active when making explicit social judgments. Switching between these two modes is rapid and can occur via either top-down or bottom-up routes. From a different perspective most of the literature, including our own studies, has focused on social attention phenomena as experienced from the first-person perspective, i.e., gaze changes or social attention directed at, or away from, the observer. However, in daily life we are actively involved in observing social interactions between others, where their social attention focus may not include us, or their gaze may not meet ours. Hence, changes in eye gaze and social attention are experienced from the third-person perspective. This area of research is still fairly small, but nevertheless important in the study of social and joint attention, and we discuss this very small literature briefly at the end of the chapter. We conclude the chapter with some outstanding questions, which are aimed at the main knowledge gaps in the literature.

4.1 Sensitivity to Eye Gaze and Social Attention: Active Brain Loci

As noted above from the first-person perspective, changes in gaze direction in someone’s face are typically associated with a change in their social attention. Hence, for the purposes of this chapter, we focus on discussing the existing literature in terms of treating changed gaze direction and changed social attention as being equivalent.

In the late 1990s, neuroimaging studies began to identify brain regions that were sensitive to viewing gaze changes in others (Puce, Allison, Bentin, Gore, & McCarthy, 1998; Wicker, Michel, Henaff, & Decety, 1998). Wicker et al. (1998) used a video in which gaze was changed to a number of different positions. There was a “mutual” condition where the stimulus face looked directly at the observer and then averted its gaze and vice versa. A similar dynamic gaze change sequence occurred in an “averted” condition, where the stimulus face altered its gaze to look at two different points in visual space (but never at the observer). Control conditions included a “no gaze” condition where the stimulus face looked down at paper on a table, and a “rest” condition, where subjects had their own eyes closed. Positron emission tomography (PET) activation was largest in the right inferior temporal and fusiform gyri (FG), and right parietal lobule, as well as in the posterior superior temporal sulcus (pSTS)/middle temporal gyrus (MTG) bilaterally, to viewing the "mutual" and "averted" conditions (Wicker et al., 1998). In another study, dynamic eye gaze changes alternating between averted and direct gaze produced strong functional magnetic resonance imaging (fMRI) activation in the bilateral STS, in bilateral hMT+, and to a lesser extent the left intraparietal sulcus (IPS) (Puce et al., 1998). These two early studies used dynamic gaze changes, unlike subsequent studies in which stimuli consisted of the onset of static faces where the gaze could be either direct or averted. Meta-analyses of studies using mainly static faces have also implicated these same brain regions as being sensitive to gaze direction/social attention. To a lesser extent, regions such as the medial prefrontal and orbitofrontal cortices, amygdala, the frontal eye fields, and a small area on the postcentral sulcus (Allison, Puce, & McCarthy, 2000; Nummenmaa & Calder, 2009; Senju & Johnson, 2009) can also be activated to gaze changes.

The seemingly disparate arrays of brain regions noted to be sensitive to direction of gaze/social attention are thought to be essential components of four separate brain subsystems (Fig. 4.1) associated with processing different aspects of social information—encompassing a single entity known as the "social brain" (Frith, 2007). These subsystems consist of four separate brain networks (see Stanley & Adolphs, 2013):

i. A mentalizing network
ii. A motor simulation/action perception network (mirror system)
iii. An empathy network
iv. An amygdala network that supports the processing of directed and relevant emotional information and its retrieval.

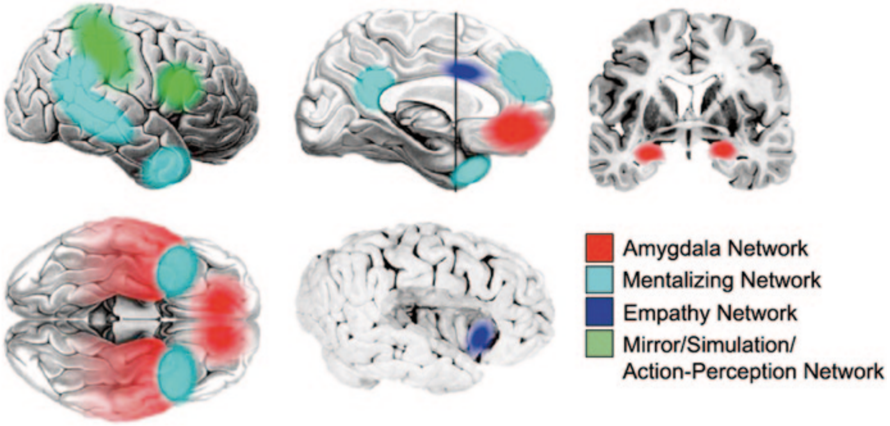

Fig. 4.1 *The social brain: four brain networks and associated component brain structures known to be active in human studies of social cognition.* Each of the four networks is depicted in a separate color, whose legend appears at the *bottom right* of the figure. (Modified, with permission, from Stanley & Adolphs, 2013).

The *mentalizing network* activates when making sense of the goals and intentions of others and consists of the pSTS (as part of the temporoparietal junction), temporal pole, precuneus, and medial prefrontal cortex (Bahnemann, Dziobek, Prehn, Wolf, & Heekeren, 2010; Frith & Frith, 2006; Stanley & Adolphs, 2013). The *mirror/simulation/action–perception network* activates when an individual executes an action, or observes another making that same action, and is thought to support action understanding, and to enable crucial abilities such as imitation and motor learning (Fogassi et al., 2005; Rizzolatti & Craighero, 2004; Rizzolatti & Fabbri-Destro, 2008) and is composed of regions of parietal and frontal cortex (Stanley & Adolphs, 2013). The *empathy network* encompasses the cortex of the anterior insula and a region bounding posterior anterior cingulate and anterior medial cingulate cortex (Engen & Singer, 2013; Fan, Duncan, de Greck, & Northoff, 2011; Lamm, Decety, & Singer, 2011; Stanley & Adolphs, 2013), whereas the so-called *amygdala network* includes the amygdala, orbitofrontal cortex, and anterior aspects of ventral temporal cortex including the FG (Olson, McCoy, Klobusicky, & Ross, 2013; Stanley & Adolphs, 2013). These brain regions and network membership are schematically represented in Fig. 4.1.

With respect to evaluating gaze direction and social attention, are some regions in the social brain more critical than others? One clue from a rare neuropsychological lesion study documents deficits in gaze processing in a patient with a circumscribed lesion involving the right superior temporal gyrus (STG) as a result of a cerebral hemorrhage. The patient could not correctly recognize left averted gaze or direct gaze, interpreting these as being direct gaze and right averted gaze, respectively. These difficulties could not be attributed to issues with visuospatial processing, as other stimuli that signaled direction, e.g., arrows, produced relatively unimpaired task performance. In the acute poststroke period, the patient had initially experienced neglect, which had recovered by the time she was tested chronically for her ongoing gaze-processing issues (Akiyama et al., 2006a, b). When also tested many years later on a visual cueing paradigm, the patient was found to be impaired only when the visual cue was provided by *gaze*, but had normal performance when the visual cue was an arrow (Akiyama et al., 2006b). An identical behavioral dissociation in cueing across gaze and arrows was also demonstrated in five patients with amygdala lesions (Akiyama et al., 2007). Although it is tempting to speculate that these gray matter regions of the brain are critical for processing information relating to social attention, it is also possible that injury to these regions may have also disrupted white matter pathways that carry this important social information. Future studies examining structural and functional connectivity in both healthy subjects and individuals with lesions will be needed to disentangle these issues.

A study of epilepsy surgery patients with depth electrodes implanted in the STS has demonstrated sensitivity to eye gaze stimuli within this brain region (Caruana et al., 2014). A patient who was cortically blind (with no viable bilateral primary visual cortex) showed greater right amygdala activation to faces with direct gaze relative to faces with averted gaze (Burra et al., 2013). These two studies indicate how critical social cues can be routed to the social brain in the absence of viable striate input, likely via extrastriate and extrageniculate routes, traveling between critical regions such as the amygdala and the superior temporal cortex.

It is tempting to speculate that the cortex of the STG/pSTS is devoted to evaluating changes in social attention/gaze in others; however, it should be noted that the pSTS is also selectively active to different types of mouth movements (Puce et al., 1998), as well as hand and leg motion (Thompson, Clarke, Stewart, & Puce, 2005; Wheaton, Thompson, Syngeniotis, Abbott, & Puce, 2004). The pSTS is known to be sensitive to biological motion in general; however, it is particularly sensitive to changes in gaze (see Allison et al., 2000 Fig. 3; Van Overwalle & Baetens, 2009 Fig. 3a and b; Itier & Batty, 2009). Importantly, the pSTS has been found to be equally active to observing pointing with the finger or the eyes (Materna, Dicke, & Thier, 2008). Overall, the data suggest that the STG/pSTS region is sensitive to the actions of others in general, rather than being only sensitive to behaviors signaling changed social attention.

In daily life the head is rarely still. Both head and eye movements are used to explore one's visual space and to direct one's own gaze to novel or relevant stimuli. Equal sensitivity to head and gaze movements has been reported in both the right pSTS and the FG (Laube, Kamphuis, Dicke, & Thier, 2010). However, the relationship of activation elicited to head versus eye movements is complicated, with interaction effects in processing head and gaze direction information having been reported. Specifically, the largest activation was observed in the right STS to a full-on face relative to an angled face, irrespective of gaze condition. Additionally, bilateral FG activation was largest to a full-on face with direct gaze (Pageler et al., 2003). In another study (George, Driver, & Dolan, 2001), greater FG activation occurred to direct gaze relative to averted gaze, irrespective of head orientation. Direct gaze also produced a greater correlation between FG and amygdala activation, whereas averted gaze produced larger correlations in activity between the FG and IPS. These activity profiles occurred irrespective of head orientation. These data indicate that direct versus averted gaze may selectively activate different subsystems within the social brain. Averted gaze has been previously associated with engaging systems related to the visual periphery, whereas direct gaze stimulates systems that deal with emotionally salient stimuli (George et al., 2001). Given that there is a redeployment of an observer's visuospatial attention in response to observing a gaze aversion in another individual, it might be expected that dorsal structures in the visual pathways might also be activated (Corbetta & Shulman, 2002)—structures that might not be involved in the processing of gaze as such. Performing experiments where task requirements are explicitly social or nonsocial might be able to further disentangle the functional neuroanatomy of a gaze aversion (e.g., see Latinus et al., 2015).

So far we have discussed activation profiles in the amygdala and the pSTS with respect to social attention stimuli. However, the middle part of the bilateral STS (mSTS) and the left anterior part of the STS (aSTS) can also show interaction effects with respect to changes in head and gaze direction. These regions have been reported to reduce their activation more when subjects followed eye-gaze direction relative to head-gaze direction (Laube et al., 2010). Laube et al. (2010) attributed the reduced activation to the "active suppression of information arising from the distracting other directional cue, i.e., head-gaze direction in the eye-gaze direction task and eye-gaze direction in the head-gaze direction task." Consistent with these data, Carlin and colleagues (2012) demonstrated involvement of the aSTS/MTG when presented with head turns in either direction, irrespective of gaze manipulation (Carlin, Rowe, Kriegeskorte, Thompson, & Calder, 2012). The various sections of the STS (aSTS, pSTS) are parts of the mentalizing network, and it appears that as one moves in an anterior direction along the STS axis, the processing of social information becomes progressively more complex (Frith & Frith, 2003).

Studies with no head direction manipulations and only gaze changes appear to show conflicting findings to viewing direct versus averted gaze: augmented activation in the pSTS has been reported to averted gaze relative to direct gaze (Engell & Haxby, 2007) and to direct versus averted gaze (Pelphrey, Viola, & McCarthy, 2004). In the former case, emotional expressions could be present on the stimulus faces, whereas in the latter case a neutral, approaching avatar was used. Indeed, changes in visually expressed social attention usually do not occur in isolation in daily life—they are often accompanied by emotional expressions that clearly indicate who, or what, the expression is being directed at. Emotional expressions themselves can produce augmented activation in the pSTS relative to neutral faces when faces are presented with direct gaze only (Engell & Haxby, 2007). Within the limbic system, increased right hippocampal activation has been found in response to faces with direct gaze, and amygdala activity has been observed in response to faces with angry expressions or direct gaze in a task requiring identity judgments. Notably, better behavioral performance (recall) of individual facial identities was associated with presented direct gaze and angry emotional expressions (Conty & Grezes, 2012).

Although the pSTS is sensitive to changes in gaze direction/social attention, the medial PFC has been found to activate to increased (direct) gaze *duration* (Kuzmanovic et al., 2009), suggesting that different parts of the mentalizing network may be involved in detecting changes in gaze/social attention versus evaluating the potential significance of the directed gaze. These data raise the question of connectivity within, and between, the different networks that make up the social brain. Recent developments in structural and functional imaging acquisition and analysis are allowing some of these relationships to be investigated. Ethofer, Gschwind, and Vuilleumier (2011) investigated the connectivity of the right pSTS with other brain regions while subjects performed a gender classification task on faces that changed with direct and averted gaze. Gaze shifts towards the observer resulted in increased functional connectivity between the right pSTS, FG, and anterior insula. Activation in the FG was equally large for faces with either directed or averted gaze (Ethofer et al., 2011). Increased functional connectivity between pSTS, MT/V5, IPS, frontal eye fields, STG, supramarginal gyrus, and middle frontal gyrus has also been demonstrated for gaze shifts relative to eye-opening and -closing movements (Nummenmaa, Passamonti, Rowe, Engell, & Calder, 2010).

The functional connectivity data allow active brain networks to be identified, but cannot speak to the underlying direct structural connections in the brain. Diffusion tensor imaging (DTI) data can allow these direct structural connections to be visualized. Interestingly, direct white matter connections have been described between pSTS and the anterior insula, but not between the pSTS and the FG (Ethofer et al., 2011). Future studies assessing both structural and functional connectivity within, and between, networks comprising the social brain will be necessary to identify which connections in the system are direct, permanent connections, and those that are fleeting (and made for the purposes of achieving a current goal via indirect routes of connectivity). These analyses might also shed some light on why there is so much variability in the literature for viewing averted versus direct gaze, and will be particularly pertinent for studies examining the deployment of social attention in different contexts.

Neuroimaging studies examining brain activation to viewed gaze changes have been informative, as they have identified active brain systems that are sensitive to the eye and gaze cues of others. However, they do not easily speak to the underlying neural dynamics of processing changes in another's gaze direction and social attention.

4.2 Evoked Neurophysiological Activity Associated with Evaluating Eye Gaze and Social Attention

Electroencephalography (EEG) and magnetoencephalography (MEG) allow the dynamics of neural processing to be studied with high temporal resolution (millisecond accuracy). To this end, neurophysiological activity that is phase-locked to the gaze/social attention stimulus can be readily identified as event-related potentials (ERPs), where multiple trials of activity within a stimulus condition have been averaged, to visualize activity with a consistent temporal relationship to the stimulus. A typical visual ERP that is elicited to a gaze stimulus consists of a triphasic ERP complex consisting of P100, N170, and P350 components (their nominal latencies in milliseconds are denoted by the numbers and voltage polarity by (P)ositive or (N)egative). These ERP components are typically maximal over the posterior scalp, with P100 and N170 seen over the occipitotemporal scalp and P350 occurring more dorsally over the parietal scalp (see Allison et al., 2000; Itier & Batty, 2009). Neurophysiological activity that is related to stimulus delivery, but that is not exactly phase-locked to stimulus onset can also be elicited to a gaze stimulus. This type of activity consists of changes in oscillatory activity in certain EEG frequencies and requires the analysis of single-trial EEG/MEG data (Tallon-Baudry, Bertrand, Delpuech, & Pernier, 1996). The bulk of existing EEG/MEG studies examining the neural correlates of viewing changes in eye gaze/social attention have reported ERP activity only; however, studies examining oscillatory changes in EEG activity across all EEG frequency bands are beginning to appear in the literature (reviewed in the second half of this section).

4.2.1 Scalp ERPs and MEG Responses Elicited to Changes in Gaze/Social Attention Viewed Without Making Social Judgments

In the first neurophysiological study to examine the effects of viewing dynamic gaze changes, we used passive viewing tasks where subjects viewed an apparent motion stimulus consisting of either a full face or isolated eyes (Puce, Smith, & Allison, 2000). The N170 ERP was significantly larger to averted gaze, irrespective of whether a full face or isolated eyes were viewed, with earlier N170s to averted gaze being seen at the right temporal scalp (Puce et al., 2000). We have replicated the N170 amplitude effect using apparent motion paradigms using full faces and tasks requiring subjects to respond to non-gaze relevant or nonsocial aspects of the viewed stimuli (Latinus et al., 2015; Rossi, Parada, Kolchinsky, & Puce, 2014; Rossi, Parada, Latinus, & Puce, 2015). Therefore, it appears that when subjects are not actively engaged in making social judgments related to face and gaze stimuli, there is modulation of N170 amplitude by the type of gaze transition (shown schematically in the top panel of Fig. 4.2).

Gaze changes in a single face viewed from a first-person perspective, such as in our experiments described earlier, limit our understanding of the overall functional significance of the neurophysiological findings. We have performed an experiment

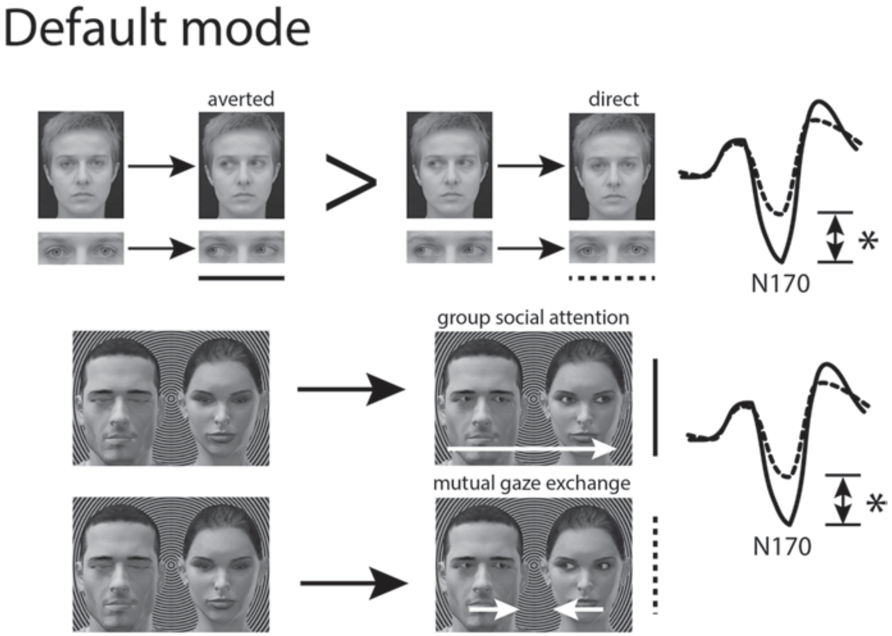

Fig. 4.2 *Schematic representation of N170 changes for the brain in* "*Default*" *mode*. The results of a number of different experiments are shown, with stimulus conditions that showed differences in N170 amplitudes being depicted on the *left* side of the figure. A schematic N170 is depicted on the *right* as showing significant amplitude differences between conditions. N170 is consistently larger to averted versus direct gaze in isolated face or eye stimuli (*top panel*), and a similar effect occurs when two faces look away from one another relative to a mutual gaze condition (*middle panel*). These N170 effects have been documented in experiments where nonsocial task requirements have been imposed. *Black arrows* between example stimuli indicate apparent motion transitions. *Solid* and *broken lines* depicting N170 waveforms are associated with particular stimuli, identified with the same line type. White arrows on images on the lower panel schematically depict the direction of the gaze change and were not present in the experiment.

to investigate social context from the point of a noninvolved observer, i.e., a third-person perspective (Ulloa, Puce, Hugueville, & George, 2014). Subjects viewed two avatar faces that were initially displayed with downcast eyes (and hence shared no "interaction" with the observer). After 1 s, the avatars changed their gaze to either look at one another in a mutual gaze situation, or look away from one another (and the observer) to a common point to one side (see middle panel, Fig. 4.2). MEG activity was recorded in response to the viewed videos (which also displayed subsequent dynamic facial emotions) while subjects looked for a cross at the center of the display to change color on a random and infrequent basis—a gaze- and emotion-irrelevant target. Significantly larger M170s (the MEG counterpart of N170) occurred when the avatars looked away to a common point relative to when they exchanged (direct) mutual gaze. These data indicate that the increased neural sensitivity to viewed averted gaze is not necessarily driven by direct engagement with, or involvement of, the observer (Ulloa et al., 2014). Critically, we have observed similar neurophysiological effects with respect to gaze aversion using *both* real images of faces and those of avatars, as well as recording neurophysiological activity across two different methods (EEG and MEG) (e.g., compare Puce et al., 2000 to Ulloa et al., 2014).

Is the gaze aversion effect modulated by the format of the face stimulus being viewed? In addition to demonstrating larger N170s to averted versus direct gaze, we have previously reported larger N170s in a passive viewing paradigm to mouth opening relative to closing movements in both real and line-drawn faces (see Fig. 4.3, top panel) (Puce et al., 2000, 2003). Similarly, fMRI activation in the pSTS did not differ between movements of the real and impoverished face (Puce et al., 2003), leading us to conclude at the time that the hemodynamic and neurophysiological response to mouth movements likely reflected a biological motion response where motion and form are integrated—similar to that observed with point-light displays of human walkers (for reviews see Blake & Shiffrar, 2007; Giese & Poggio, 2003; Puce & Perrett, 2003; Puce et al., 2015).

More recently, we investigated eye movements in parallel with mouth movements in impoverished (line-drawn) faces and replicated the N170 amplitude effect for viewing mouth opening versus closing movements, but saw *no* significant differences in N170 between averted and directed gaze to line-drawn faces (see Fig. 4.3, lower panel; and Rossi et al., 2014). One potential reason for the lack of N170 differentiation across impoverished eye movements could have been that these effects were dependent on local visuospatial changes in stimulus luminance/contrast, given that the human eye consists of a high-contrast iris–sclera complex (Rossi et al., 2014). An alternative possibility could be an effect of experimental context: where the presence of real faces in the previous experiment (i.e., Puce et al., 2003) may have influenced the N170 to the impoverished faces (Rossi et al., 2015). Strong stimulus context effects for N170 have previously been reported for face and fragmented face stimuli (Bentin & Golland, 2002; Jemel, Pisani, Calabria, Crommelinck, & Bruyer, 2003; Latinus & Taylor, 2006).

Additionally, our line-drawn face motion experiment also produced different patterns of neural activity depending on whether the baseline stimulus (of a direct

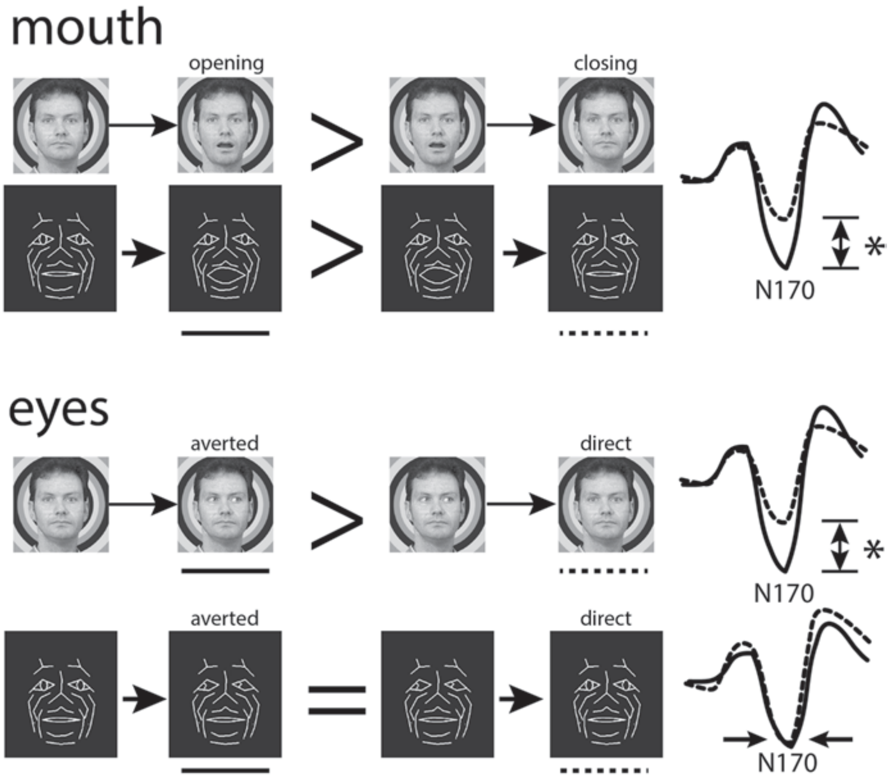

Fig. 4.3 *Schematic representation of N170 changes to different types of facial movements.* Mouth movements elicit N170 amplitude changes, irrespective of what type of face stimulus depicts the facial motion: larger N170s are seen to mouth opening relative to mouth closing movements (*top panel*). Eye aversion elicits larger N170s relative to direct gaze in real faces only. N170 amplitudes do not differ when gaze transitions are represented by line-drawn faces (*lower panel*). These N170 effects have been documented in experiments where nonsocial task requirements have been imposed. *Black arrows* between example stimuli indicate apparent motion transitions. *Solid* and *broken lines* depicting N170 waveforms are associated with particular stimuli, identified with the same line type.

gazing face with mouth closed) was preceded by a gaze aversion or a mouth opening movement (Rossi et al., 2014). So as to disentangle these potentially different explanations for our data, we presented gaze changes in stimulus blocks using real and impoverished faces (Rossi et al., 2015), in a similar design to what we had used for mouth movements in real and line-drawn faces (Puce et al., 2003). N170s to real faces were larger to averted gaze relative to direct gaze (replicating Puce et al., 2000 and Latinus et al., 2015), however, N170s to impoverished faces did not differ in amplitude across gaze conditions (replicating Rossi et al., 2014) (see Fig. 4.3, bottom panel). Hence, experimental context (with respect to impoverished and real faces) does not appear to drive the modulation of N170 to dynamic face transitions. Taken together, our ERP data across these multiple studies indicate that

N170s that differentiate between types of eye and mouth movements are probably being generated by two very different neural mechanisms. Specifically, we are making the claim (Puce et al., 2015; Rossi et al., 2015) that:

1. The differential N170 elicited to mouth movements likely represents a biological motion response, elicited to viewing *articulated* human motion. Mouth opening/closing movements are produced by the action of an articulated mandible. Despite the changing contrast between the teeth and lips when the mouth opens and closes, this response is clearly not entirely dependent on stimulus luminance/contrast since it is also elicited to mouth movements in line-drawn faces.
2. The differential N170 elicited to direct versus averted gaze in a real face is produced by a high luminance/contrast change in visual space produced by the movement of the human iris–sclera complex. This effect is abolished when eye gaze is represented by schematic eyes in line-drawn faces with overall low luminance/contrast. Eye movements (and generally movements of the upper face) are not an articulated form of human motion, and therefore elicit a neural response that is different from that of an articulated motion stimulus. Experiments varying luminance and contrast in schematic eye stimuli would be needed to verify these claims.

Consistent with the idea that N170 is affected by changes to high-contrast eyes are data from a study in which we investigated the neural consequences of viewing another's gaze changes compared with eye closure and eye blinks (Brefczynski-Lewis, Berrebi, McNeely, Prostko, & Puce, 2011). Subjects responded to a target stimulus consisting of a checkerboard pattern superimposed on the continuously displayed face. We had originally predicted that given the potential social significance of gaze transitions, N170s to gaze aversions would be significantly larger than those to eye blinks and eye closure. To our surprise, N170 did not differ as a function of these conditions (Brefczynski-Lewis et al., 2011). However, in all of these stimulus conditions the high-contrast direct gaze was replaced by a stimulus condition with altered local visuospatial contrast. Specifically, direct gaze could change to either averted gaze or closed eyes (depicting either a blink [brief] or eye closure [a longer interval]). For a given pixel in the region of the iris/pupil of the stimulus image, there is a luminance change in the transition from eye opening to eye closure.

Does the size of the gaze transition or the physical direction influence the observed neural response? Human observers can reliably detect 1–3° changes in another's gaze (Anderson, Risko, & Kingstone, 2011). Given that we have found that low-level factors affect the neural response to viewed gaze movements, it is conceivable that the N170 might also be sensitive to the size of the gaze transition. Extreme gaze aversions, e.g., 30° from the direct gaze position, might generate larger N170s than smaller gaze transitions, e.g., of 15°. In a recent experiment we included stimuli with different sizes of gaze transitions and explicitly looked for modulation of N170 as a function of size of gaze excursion. However, N170 did not differ with size of gaze transition (Latinus et al., 2015). In our earliest study investigating N170 to eye gaze changes, we also explicitly examined our data for gaze transitions occurring to the left and right. N170 was not affected by the physical direction of the gaze movement—N170 amplitudes were not significantly different to viewing gaze changes to the left or the right of the observer (Puce et al., 2000). From these two studies we conclude that, although the N170 is likely generated by a local visuospatial change in luminance/contrast, the physical direction and the size of the gaze transition, as seen in a real face, do not modulate this neurophysiological response. If this is the case, then what does an N170 ERP signal reflect when it is elicited to a gaze change? The previously described experiments cannot address this question (with the exception of Latinus et al., 2015), as they all were either passive viewing paradigms or used tasks where target stimuli were gaze-direction irrelevant.

4.2.2 Scalp ERPs and MEG Responses Elicited to Changes in Gaze/Social Attention Viewed While Making Social Judgments

The previous sections have focused on the effects of gaze changes in situations where social judgments were not required. However, as the studies reviewed subsequently indicate, neural activity will be quite different depending on the type of judgment that is made on the gaze stimulus.

Conty et al. (2007) performed an experiment in which subjects made explicit social judgments related to the direction of the observed gaze change. Their experiment had a trial structure that is shown in Fig. 4.4. A stimulus pair was presented on each trial, producing an apparent motion gaze transition, with the first stimulus always showing an averted gaze at an intermediate position (15°). The subject was asked to indicate with a button press whether the gaze transition induced by the presentation of the second stimulus moved towards them or further away from them. Hence, the subject made a *social judgment* regarding the gaze change in the observed faces. The subject could not predict whether the next stimulus would be a direct gaze or an even further (30°) gaze aversion. Head position was also varied in the experiment, resulting in a 2 × 2 design for head (full-on, ¾ view) and eye (averted, direct) position. Interestingly, N170 to *direct* gaze transitions was significantly *larger* relative to transitions where the gaze aversion became more extreme, irrespective of head position. These data were consistent with an interpretation that N170 signals change in social attention. In the case where the gaze is already averted and then becomes more extremely averted, there is no net change in social attention with respect to the observer, so therefore there would be no differences in N170 amplitude (Conty, N'Diaye, Tijus, & George, 2007). These data are extremely interesting and appear to be at odds with the ERP data that we have reported using extreme gaze aversions and direct gaze in a series of studies (Latinus et al., 2015; Puce et al., 2000; Rossi et al., 2014).

So as to try and reconcile the differences in N170 data between our two laboratories, we performed two experiments using a subset of stimuli from Conty et al.

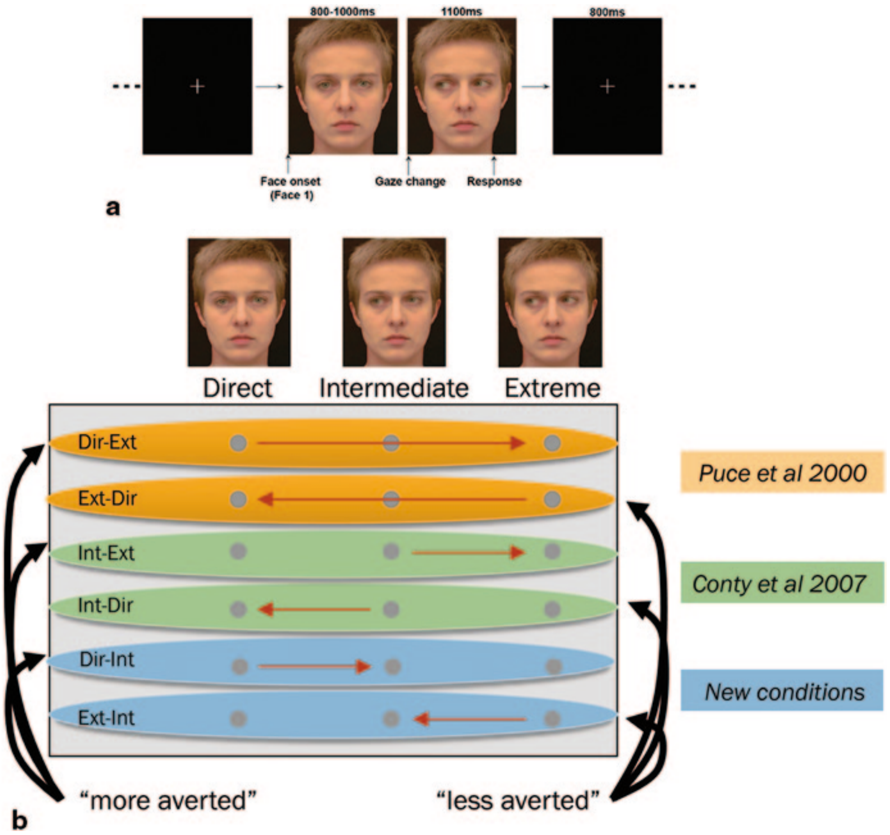

Fig. 4.4 *Experimental trial structure (**a**) and stimulus conditions (**b**) from a social attention experiment.* **a** Subjects viewed a display where a central fixation cross was replaced by a face (with varied positions of gaze). After a short interval the face changed its gaze and subjects were required to press one of two buttons to evaluate the gaze change. In a nonsocial task, subjects judged if the gaze change occurred to their left or their right, whereas in a social task subjects indicated if the gaze change moved towards them or away from them. **b** Stimulus conditions consisted of gaze changes previously studied by Puce et al., 2000 and Conty et al., 2007, and are displayed as red arrows between the grey circles in each of the 6 tested gaze transitions. So as to have a balanced design with respect to gaze changes, two new (previously untested) conditions were also included in the experiment. The gaze change can be regarded as becoming "more averted" or "less averted"—as shown by the thick black *arrows* identifying the respective stimulus conditions where this is the case.

(2007) consisting of gaze transitions in full-on faces (see Latinus et al., 2015). We opted to run two experiments (with counterbalanced order) in the same subjects using identical stimuli, using two different types of judgments—an overtly social and a nonsocial one. The nonsocial task consisted of subjects indicating with a button press whether the gaze in the stimulus face moved to the *left* or *right* of them. In the social task, subjects indicated whether the gaze moved *away* or *towards* them (identical to the task used by Conty et al., 2007). (One could make the argument that all stimuli involving faces are inherently social. We, however, are making the distinction here with regard to the type of judgment that the subject has to make on the incoming stimulus.) When subjects made a *nonsocial* judgment, N170s to any gaze transition where gaze became more averted were significantly larger relative to gaze transitions moving towards the subject. This occurred for stimuli depicting both direct gaze and intermediately averted gaze. These changes were observed in the bilateral occipitotemporal scalp. Notably, when subjects made *social* judgments, N170s were no longer significantly different across gaze conditions in the right occipitotemporal scalp (see Fig. 4.5, bottom panel). In contrast, N170s in homologous sites in the left hemisphere were identical, irrespective of the social judgment: more extreme gaze aversions produced larger N170s relative to gaze transitions whose gaze was direct or less averted. These data strongly indicate that the right hemisphere is selectively engaged while making explicit social judgments of another's altered social attention. Hence we were able to replicate our previous studies (Puce et al., 2000; Rossi et al., 2014), which examined extreme gaze changes in real faces (Fig. 4.5, top panel).

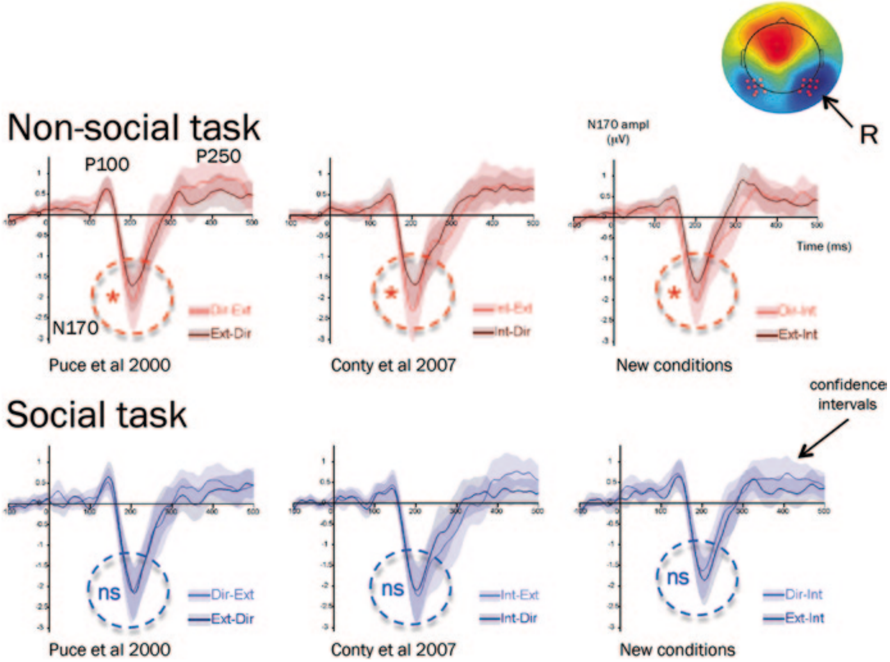

Fig. 4.5 *Group data from a social attention experiment where N170 ERP modulation occurred as a result of a nonsocial versus social decision from stimulus conditions shown in* Fig. 4.4. ERP data were obtained from a nine-electrode cluster overlying the right occipitotemporal scalp. N170 amplitude modulation as a function of more averted gaze occurs in all tested conditions in the right hemisphere on the nonsocial task. This N170 difference is abolished when subjects engage in an explicit social judgment in the social task. In the left hemisphere (not shown), N170 amplitude modulations occurred for more averted gaze positions for *both* nonsocial and social decisions. (Modified from Latinus et al., 2015).

We did not exactly replicate Conty et al. (2007) in this study, who found that N170s to direct gaze were larger relative to extreme aversions when made from an intermediate averted gaze position. Given that interactions in head and gaze position are known to occur in both fMRI and neurophysiological studies (as discussed earlier), it is possible that there may have been some additional N170 modulation as a function of head position in the original 2007 study of Conty et al. (Latinus et al., 2015). Itier and colleagues (2007) have noted a complex set of interactions in N170 amplitude data between head and eye gaze positions when subjects had to make judgments related to *either* head or gaze position. Interestingly, N170 activity to viewing static eyes in faces is also modulated by where the viewer's gaze falls on the face: if the viewer fixates their gaze on the eye, N170 amplitude will be larger than if another area on the face is viewed (see Nemrodov, Anderson, Preston, & Itier, 2014). There appears to be a very complex relationship between the focus of one's own social attention and point of gaze on another's face, which may be additionally modulated by the viewed face's head and eye positions. An additional important source of variation may come from the reflexive alteration of an individual's visuospatial attention when they observe a gaze change. To disentangle these relationships would likely require a series of experiments where these variables were varied parametrically using face and non-face stimuli.

4.2.3 Two Different Modes for Processing Another's Gaze Direction: A Proposed Model

The data from Latinus et al. (2015) and the other studies reviewed here argue for the existence of potentially different modes of processing of social information in the brain. We would like to make the claim that our brains have two modes: a "*Default*" and "*Socially Aware*" mode. It would be possible to switch rapidly between one mode and the other—with an active mode at a particular instant being activated in response to one's current goals and actions. We describe these two modes below.

In Default mode, the subject is not explicitly focusing on, or may not even be aware of, the social meaning of the stimulus. Experiments featuring tasks with passive viewing, or depicting facial movements as irrelevant targets, would fall into this category (e.g., Puce et al., 2000; Ulloa et al., 2014). Similarly, in everyday life we go about our business with an internal focus on our own goals and future actions, irrespective of what others around us might be doing. As we have already discussed in detail earlier, sensory neural responses, e.g., N170, will differ across types of facial movements because of low-level characteristics such as changes in local luminance and contrast (iris/sclera movements) and biological motion (from articulated mouth movements) (see Fig. 4.2) in the Default mode.

In contrast, a Socially Aware mode would occur as a result of having to make overt social judgments, such as where another's gaze direction must be explicitly evaluated by the observer relative to himself or herself. In everyday life, we might attend to the feelings and emotional state of another, where their facial movements serve as important cues. In Socially Aware mode, our sensory systems are

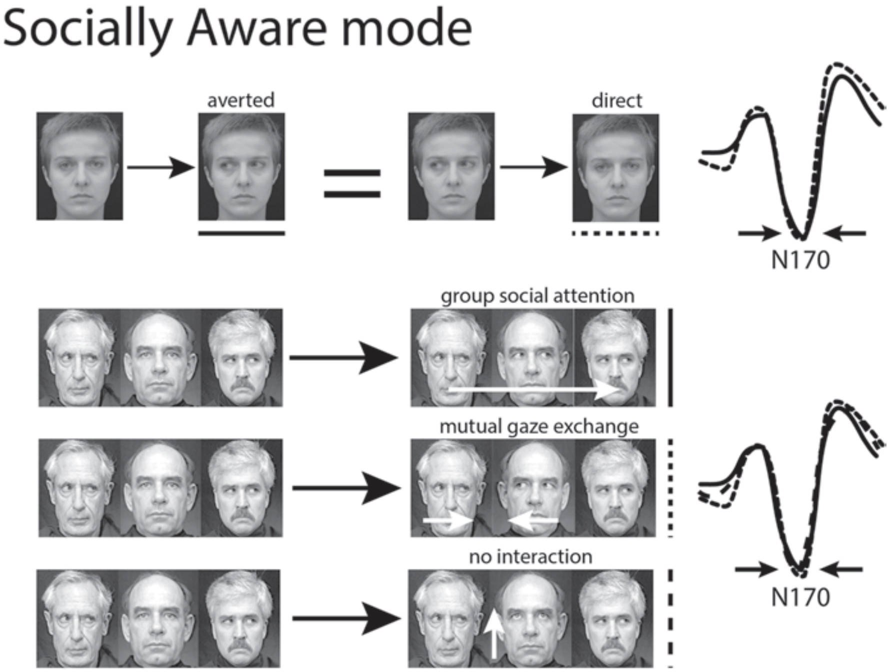

Fig. 4.6 *Schematic representation of N170 changes for the brain in "Socially Aware" mode*. The results of two experiments are shown. Isolated faces with gaze changes produce N170 amplitudes of equal magnitude when subjects are required to make social judgments relating to the direction of gaze (*top panel*). Similarly, when subjects make judgments on the type of social interaction that is taking place when a central face changes its gaze in a triad of faces, N170 amplitude is equal across conditions. *Black arrows* between example stimuli indicate apparent motion transitions. *Solid* and *broken lines* depicting N170 waveforms are associated with particular stimuli, identified with the same line type. White arrows on images on the lower panel schematically depict the gaze interaction of the central face with flankers and were not present in the experiment.

maximally primed, allowing incoming sensory information to be optimally processed. It is as if the gain in the sensory system has been increased to allow more complete social evaluations of incoming stimuli, which would be indexed by ERPs that follow the N170. Neurophysiologically, this would manifest as sensory ERP components, i.e., N170, with equal amplitudes across conditions (see Fig. 4.6), enabling better subsequent processing and differentiation in later (endogenous) ERPs. Socially Aware mode would be particularly important in reading situations where multiple individuals share an interaction. In one of our previous studies (Carrick, Thompson, Epling, & Puce, 2007), subjects made explicit social judgments from sets of face triads with dynamic gaze changes producing one of three different social situations (see the lower panel, Fig. 4.6). The dynamic gaze transition produced N170s of identical amplitude across all conditions—consistent with increased gain in visual pathways—while subsequent ERP activity beyond 350 ms poststimulus differentiated between social conditions.

The switch from one mode to another could be made effortlessly and rapidly by top-down or bottom-up mechanisms. Bottom-up mechanisms operating from signals in areas such as the amygdala might be involuntary and may not be available to conscious awareness (e.g., Hardee, Thompson, & Puce, 2008). Top-down mechanisms, on the other hand, would be voluntary and governed by current intended goals and task demands. What exactly leads to a switch to a socially aware mode remains an open question. Although it seems obvious that explicitly asking participants to make social judgments would put subjects into this mode, other less explicit instructions or task requirements may well have the same effect. For instance, Ponkanen, Alhoniemi, Leppanen, and Hietanen (2011) reported larger N170 to direct than averted gaze with live faces, but not with pictures of faces. This may suggest that just seeing real faces rather than pictures may be sufficient to induce the Socially Aware mode. Another way to switch to a Socially Aware mode might simply occur by seeing a face that conveys emotion.

These different modes of information processing are likely not restricted to facial motion, but would extend to movements of the hands and body. Indeed, in a very early study, we have demonstrated significant differences in early ERPs (including not only N170 but also other components that occur at around 200 ms, or earlier, post-motion onset) to hand opening and closing movements as well as leg movements. Specifically, hand closing movements, i.e., making a fist, generated an ERP at around 200 ms (N170) post-motion onset from mainly the left temporal scalp, which was significantly larger than that elicited to hand opening movements (Wheaton, Pipingas, Silberstein, & Puce, 2001). Interestingly, in the same study we also noted significantly larger ERPs from the central scalp (a positive potential at 130 ms post-motion onset, and another positivity at around 270 ms) to viewing a leg stepping forward (i.e., an approach behavior) to a leg stepping back (Wheaton et al., 2001). In Default mode, our brain systems are not socially engaged, but nevertheless could be sensitive to incoming stimuli that are potentially threatening. The enhanced N170s observed to hand closure (a fist), a step towards us, a gaze aversion, or an opening mouth relative to other movements of the same body parts might be generated with the assistance of (subcortical) systems that detect potential threat (Bishop, 2008; Mulckhuyse & Theeuwes, 2010; Porges, 1997). The differentiation of the earlier neural responses to these types of important stimuli would enable us to potentially pay more attention to our surroundings and force us to evaluate our environment.

Where does the salience of the gaze stimulus fit into this picture? Others have argued that direct gaze is a much more *socially salient* stimulus relative to averted gaze (Conty et al., 2007; Ethofer et al., 2011; Itier & Batty, 2009). Direct gaze is a cue that informs an observer that there is a desire to communicate (Kleinke, 1986). As such, one might expect early ERPs to be modulated in the direction favoring direct gaze given this consideration. On the other hand, as argued earlier, when it comes to threat detection an averted gaze stimulus may also have increased salience (producing altered visuospatial attention and a subsequent reevaluation of the visual environment). To date, there are relatively few studies examining the neurophysiological dynamics that occur to viewing the movements of others under different social manipulations, and more studies are needed to try and disentangle what might be multiple neural mechanisms (social, nonsocial) that might operate in parallel.

When in Default mode, the subject is typically not overtly and explicitly focusing on evaluating social information. This does *not* imply that it is not possible for this to occur in this mode: later (endogenous) ERP activity is still elicited and can potentially show differences between stimulus conditions, but this activity might not be actively used in the current situation. The fact that late ERP activity has been elicited would be optimal should a sudden switch to Socially Aware mode be required, where what was seen could be reevaluated, i.e., generating an internal social type of "double-take." Below we provide some examples of later ERPs elicited to situations of social attention.

Two of the studies we described earlier (Carrick et al., 2007; Latinus et al., 2015) have had subjects that make explicit social judgments, i.e., operate in Socially Aware mode. In Carrick et al. (2007), a central face averted its gaze from the viewer while two flanker faces were depicted with unchanged averted gaze, and subjects pressed a button to indicate where the central face "shared an interaction" with none, one, or both flanker faces. We recorded two later ERPs in this paradigm. We observed a P350 with a prominent midline central scalp distribution, and also a subsequent P500 that showed a midline parietal scalp topography. Importantly, these later ERPs were sensitive to social situation: P350 was larger to the two conditions where a social interaction was taking place (relative to a situation where the face ignored the two others). P500, on the other hand, was significantly larger to the condition where the central face "ignored" the two others (Carrick et al., 2007). In Latinus et al. (2015), subjects made social and nonsocial judgments. However, we were able to elicit reliable late ERPs that showed main effects as a function of task (social, nonsocial), gaze direction (averted, direct), and their interactions that were seen over large areas of the scalp. This was particularly true for gaze direction—with the largest changes occurring between conditions at latencies of around 375 ms post-gaze change (Latinus et al., 2015).

Future studies evaluating social attention changes in stimuli would potentially be more informative if two types of task were used in the same subjects using the same stimulus set in a single experimental session. In an explicit task where a social judgment is required, it is likely that the later endogenous ERPs would be informative and show changes that are consistent with social dimensions in stimulus conditions. It would be expected that sensory ERPs would show equal amplitudes across conditions. In implicit tasks with nonsocial task demands, sensory ERPs (e.g., N170) would be driven by low-level stimulus differences, whereas later endogenous ERPs would not differentiate as strongly across this passive dimension. By running implicit and explicit social tasks in the same experimental session, some of the variable differences in the social cognition literature might be reconciled. This multi-task approach is yielding interesting results in the areas of emotion processing and intentionality (Rellecke, Sommer, & Schacht, 2012) in that modulation in ERP components is observed only when subjects engage in gender and emotion discrimination tasks, but not in passive viewing. In this study, P100, N170, and slow-going and diffuse ERPs such as the late positive complex (LPC) were studied. Similarly, Wronka and Walentowska (2011) have observed N170 differences between faces depicting emotions relative to neutral, but these differences were not present when subjects performed a gender discrimination task (Wronka & Walentowska, 2011). If more of these multi-task studies were performed, then we might be able to gain a better understanding of the functional significance of various neurophysiological components.

4.2.4 Neural Responses Elicited to Changes in Gaze/Social Attention in the Presence of Emotional Facial Expressions

So far we have discussed changes in neurophysiological activity to eye gaze/social attention manipulations that have occurred in faces without associated emotions being presented. Facial expressions are usually directed at specific individuals, so changes in their gaze/social attention send a clear signal to others as to who is the target of the directed emotion. Therefore, it would not be unexpected to find interactions between gaze direction and associated facial emotion. Similarly, there may be differences in interaction effects elicited to gaze change/emotion pairings that reflect social stimuli that are likely in real life to produce approach versus withdrawal behaviors in the observer. Quite different neural responses might be elicited between averted gaze in a fearful face versus a direct gaze in an angry face. Both stimuli signal a potentially threatening situation, but likely have different contexts, despite eliciting likely withdrawal behaviors.

A number of fMRI studies have examined the neural processing underlying gaze aversions and displays of emotional facial expressions. Boll et al. (2011) found that angry faces with direct gaze elicited stronger amygdala activation relative to angry faces with averted gaze, i.e., anger targeted at another person. They demonstrated the opposite pattern with fearful faces, in that fearful faces with averted gaze elicited greater amygdala activation relative to fearful faces with direct gaze (Boll, Gamer, Kalisch, & Buchel, 2011). Similar to angry faces with direct gaze, happy faces with direct gaze also elicit more robust activation relative to the same emotional expressions presented with averted gaze (Sato, Kochiyama, Uono, & Yoshikawa, 2010). Indeed, direct gaze in faces that are rated as being attractive can also produce greater activation in the amygdala, relative to averted gaze from those same attractive faces (Kampe, Frith, Dolan, & Frith, 2001). Taken together, the findings of these studies and those of George et al. (2001) discussed earlier suggest that the amygdala maintains a sensitivity to the most salient combination of gaze–emotion signals that are related to explicit approach/avoidance behaviors (Adams & Kleck, 2005; Hietanen, Leppanen, Peltola, Linna-Aho, & Ruuhiala, 2008).

It appears that individual differences in anxiety may modulate the amygdala response to salient gaze–emotion stimuli: individuals who were high on the anxiety scale showed the greatest activation to angry faces with direct gaze, but did not differ in their response in the gaze manipulation of fearful faces (Ewbank, Fox, & Calder, 2010). It should be noted that selective amygdala activation can be elicited by isolated eyes depicting fear with direct gaze: selective activation occurred in the right amygdala in an experiment in which these stimuli were task-irrelevant. In contrast, the left amygdala in the same study was sensitive to all types of changes in the eyes, be it gaze direction, eye widening or narrowing, or change in spatial position of the eyes (Hardee et al., 2008). From these data, it appears that our amygdalae are responsive to changes in gaze, or changes in the eyes that occur when producing emotional expressions, irrespective of whether these are being actively attended to, or whether they are task-relevant.

Neurophysiological studies have the potential advantage over fMRI, as they have the ability to *temporally* isolate the neural response related to the gaze change from activity generated to the viewed emotion. Importantly, the observed effects from viewing these compound types of stimulation may differ depending on the order in which the dynamic changes in the face occur—as two studies we review below suggest.

Dumas et al. (2013) recorded MEG activity elicited to the onset of isolated static faces with direct gaze showing either a fearful or neutral expression from a gray background. The experiment was set up as a 2 × 2 stimulus design where Expression (Fearful, Neutral) and Gaze (Direct, Averted) were manipulated, and ERP activity to the onset of each static face could be recorded. Rather than measuring ERP peak amplitudes and latencies, changes in evoked activity were expressed as significant differences between ERP waveforms at various time intervals. Subjects' anxiety levels were assessed and used as a co-variate in the data analyses. Subjects responded to a gaze/emotion-irrelevant target, in the form of an infrequently presented blue dot that would appear after the offset of either face stimulus, ensuring that target-related ERP activity would not impinge on the effects of interest. Neural source modeling generated time courses of putative neural activity in neocortex (ventral and lateral superior temporal cortex) and amygdala. Putative amygdala activity for fearful relative to neural faces was enhanced between 130–170 and 310–350 ms, and that to direct versus averted gaze was enhanced between 190 and 350 ms. This latter activity was selective for fearful faces in the right amygdala. Activity in neocortical sources occurred in parallel with that of the amygdala in the M170 range. The ventral cortical responses were also modulated by emotion, with greater activity to fearful relative to neutral faces (Dumas et al., 2013). This study indicates how complex potential interactions between gaze and emotion can be. Given that the manipulation of emotion and gaze direction was concurrent, in this study it is difficult to separate out neural effects to gaze changes or to emotion.

Earlier we discussed the data of Ulloa et al. (2014) with respect to neural activity elicited to gaze changes. Unlike in the experiment of Dumas et al., Ulloa et al. presented a gaze change in two flanking neutral avatar faces 1 s *prior* to the onset of a dynamic emotion in both faces that evolved and waned over a further 4 s period, allowing neural activity to elicited gaze changes and viewed emotions (happy and angry) to be separated. Gaze change conditions included a mutual gaze condition and a condition where the avatars looked away from one another (and the observer) to a point to the side of the screen. As noted earlier, irrespective of the subsequent emotion, gaze changes elicited larger M170 activity when the avatars averted their gaze from one another (and the observer) relative to the mutual gaze condition. To examine neural activity to the dynamic emotion, it was necessary to evaluate changes in mean MEG activity over time, as effectively no ERP activity would be observed to a continuously changing face depicting an emotion over a 4 s period. Main effects of emotion were observed in two MEG sensor clusters—one over the occipital scalp and the other anteriorly over the right frontotemporal scalp. In the posterior cluster these effects ranged from 400 to 1300 ms, with activity in the right cluster being more prolonged. There was no main effect of gaze condition when the emotions were unfolding (these effects had occurred earlier to the initial gaze change). Interestingly, there was a three-way interaction between gaze condition, emotion, and hemisphere of recording that occurred at two time intervals: 100–400 and 1000–1900 ms post-expression onset. Post hoc comparisons indicated that these effects in the later range were driven mainly by activity in the *left hemisphere for the mutual gaze condition* for both emotions. In contrast, activity differences in the right anterior MEG sensor cluster were quite complex, with the earliest main effects occurring for gaze condition in the 100–400 ms post-expression onset time range, and effectively persisting until the end of the presented emotion (until 2500 ms). An interaction effect between gaze condition and emotion began at around 700 ms, also effectively persisting until the end of the presented emotion. Further testing identified the mutual gaze condition, and also the angry expression as being the drivers for these differences (Ulloa et al., 2014). The data from this study demonstrate how complex the interactions in gaze and emotional expression can be, and that they can also be separated in time from the original gaze change.

The data from this study indicate a clear set changes in brain activity that emerge over time: the initial gaze change in a neutral face was diminished when the two faces were not engaged in mutual gaze (larger M170 to averted conditions) in the posterior scalp. As the emotion unfolded (and gaze remained constant) bilateral activity played out across the posterior sensors until about halfway through the depicted emotion (i.e., at its peak). Effects in the right anterior sensors, once active, persisted for the presentation of the whole emotion. Notably, there was an interaction effect between gaze condition and emotion, with the mutual gazing faces with angry expressions showing the greatest prolonged MEG activity. The data from this study raise many questions. One main question that cannot be answered from this study relates to the *frequency composition* of the increased MEG activity elicited to the stimulus manipulations.

4.2.5 Evoked Intracranial EEG Activity to Viewing Changes in Gaze/Social Attention

Scalp EEG and MEG studies cannot localize the sources of neural activity with certainty, although neural source modeling is performed on these types of data (for a review, see Michel et al., 2004). On rare occasions neuroscientists have the ability to record neurophysiological activity directly from the human brain in neurosurgical patients who are undergoing invasive investigations for the amelioration of drugresistant seizures, often of temporal lobe origin. Although there is always the question of how this activity might be affected by either an underlying tissue abnormality or anticonvulsant medication, nevertheless these types of recordings provide a window onto the brain. As discussed in Sect. 4.1, fMRI studies have identified active brain loci for processing information related to gaze and social attention changes. This has led some investigators to study neurophysiological activity in these brain regions in neurosurgical patients whose seizure semiology dictates the placement of intracranial recordings in these brain regions.

Caruana et al. (2014) examined intracranial ERPs, as well as oscillatory gamma band EEG activity to viewing gaze changes produced by apparent motion, similar to our previous studies. Epilepsy surgery patients viewed the stimuli and pressed a button whenever the stimulus face closed its eyes. Over 200 recording sites from depth electrodes penetrating all gyri of posterior temporal cortex (superior, middle, and inferior) and angular gyrus were studied. Notably, significantly greater neurophysiological activity was observed to averted gaze relative to direct gaze or to a side switch gaze change, where gaze changed from extreme left to extreme right, or vice versa. Both intracranial N170 amplitudes and high gamma band power (50–150 Hz) were significantly increased to the gaze aversions that followed from a direct gaze position, and these changes were seen on depth electrode contacts centered on the MTG. According to the authors the "crucial aspect of gaze aversion is the prior presence of the eye contact and its interruption" and that this was the likely reason for the resulting augmented neurophysiological activity as shown by both intracranial N170 ERP and high gamma band activity (Caruana et al., 2014).

Increased intracranial ERP activity has also been reported in recordings made from ventral temporal cortex, i.e., FG, to averted versus direct gaze. N200 ERP amplitude was increased to averted versus direct gaze, in an experiment where head position was also manipulated (Pourtois, Spinelli, Seeck, & Vuilleumier, 2010) similar to that performed originally by Conty et al. (2007). Unlike in Conty et al. (2007), the only main effect that was observed was for gaze—no significant differences were observed in head position. Pourtois et al. also reported a late ERP effect in the FG, where larger activity beginning at around 400 ms and lasting for around 600 ms was observed to averted versus direct gaze in a task where the patients were required to perform a gender discrimination task. Similar to the scalp ERP data, the intracranial data show an initial early effect of gaze transition (at around 200 ms) followed by later ERP effects that begin after 300 ms (Pourtois et al., 2010).

Given our Default/Socially Aware information-processing model outlined in the previous section, it will be interesting to perform more invasive studies from these brain regions that compare neurophysiological changes to social and non-social tasks in the same individuals. Scalp EEG studies have poor localization value, and invasive EEG studies (despite having limited placement that is dictated by clinical demands) can identify local neurophysiological activity from the presence of large local amplitude gradients and polarity reversals in neural activity.

4.3 Oscillatory EEG Changes Elicited to Viewing Changes in Gaze/Social Attention

A growing number of laboratories, including our own, are beginning to investigate the frequency composition of EEG/MEG activity elicited to viewing changes in social attention. Averaged ERP activity tells only part of the story when examining neurophysiological effects that are produced by any incoming stimulus. Very few studies to date examine ERP and oscillatory activity side by side, so currently it is difficult to get a sense of how brain activity changes overall with respect to viewing changes in gaze/social attention. This is an important issue, because fMRI activation is likely to be a composite of both types of neurophysiological activity (e.g., Logothetis et al., 2001; Puce et al., 1995, 1997), potentially producing different results across assessment modalities. At this stage, we currently still lack an understanding of the true functional significance of neurophysiological activity elicited to changes in the social attention of others. Similarly, the functional neuroanatomy of social attention needs to be placed explicitly within the context of known networks that make up the social brain, i.e., mentalizing network, amygdala network, mirror neuron network, and empathy network (Stanley & Adolphs, 2013). As seen in the previous sections of this chapter, the literature to date implicates mainly the mentalizing and amygdala networks as being crucial to evaluating another's social attention.

As we noted in the previous section, Caruana et al. (2014) documented increased high gamma band power to gaze aversions that occurred from direct gaze transitions, in addition to their increased intracranial N170s to averted gaze. What is not clear is whether there were changes in other frequencies of oscillatory EEG activity in this study, e.g., in the alpha and beta ranges in the temporal cortex.

In two studies, we recorded ERPs and oscillatory EEG activity in response to viewing faces depicting eye gaze changes in a nonsocial task. In one experiment, stimuli consisting of only line-drawn faces were presented (depicting eye and mouth movements) (Rossi et al., 2014), and in the second experiment real images of faces and line-drawn faces were presented in the same experiment (Rossi et al., 2015). We have already described the ERP features in detail to these experiments above where N170 increases to gaze aversions were observed only to images of real faces. Relevant to the current discussion, we evaluated oscillatory EEG activity over a 5–50 Hz range, segregating the activity into alpha (8–12 Hz), beta (12–30 Hz), and low gamma (30–50 Hz) frequency bands. We looked for significant differences between direct gaze and averted eye conditions in both studies. In the study in which only line-drawn faces were presented, changes in the beta and gamma band were observed. Beta band (12–30 Hz) power increases are thought to reflect maintenance of current behaviorally relevant sensorimotor or cognitive states (Engel & Fries, 2010). Gamma band (>30 Hz) power increases have been associated with facilitation in cortical processing in situations requiring cognitive control and perceptual awareness (Engel & Fries, 2010; Grossmann, Johnson, Farroni, & Csibra, 2007; Ray & Cole, 1985; Tallon-Baudry & Bertrand, 1999, but see

Sedley & Cunningham, 2013). In our recent studies, averted gaze relative to direct gaze elicited suppressed beta activity at two discrete time points: around 150 and 350–450 ms post-gaze transition in the left occipitotemporal scalp. Additionally, beta activity increased at this latter time interval over the right occipitotemporal scalp for the averted relative to direct gaze comparison. In the left hemisphere, a relative increase in low gamma activity was noted to direct gaze at around 450 ms. These changes in oscillatory activity to the eye gaze stimuli were very different to those observed to mouth movements and to movements of scrambled control stimuli. For mouth movements, reduced activity at around 500 ms was seen in the gamma range for mouth closing versus opening movements in both hemispheres, with an increase in beta activity at around 380 ms in the right occipitotemporal scalp occurring to mouth closing versus opening. Motion control stimuli produced a different pattern to either eye or mouth movements, with brief changes in activity occurring only in the left occipitotemporal scalp in the beta range at ~425 ms and the gamma range at around ~100 and 380 ms (and with a higher frequency in the lower gamma range). In this study, participants were asked to respond on each experimental trial with a button press to indicate whether the current line-drawn stimulus was white or red (Rossi et al., 2014).

In our second study examining oscillatory EEG changes in both real and line-drawn faces, participants detected an infrequent target stimulus that could be a photonegative image of each of the different stimulus types (Rossi et al., 2015). We presented blocks of real and line-drawn faces depicting gaze aversions and direct gaze transitions to look for effects of experimental context on neurophysiological activity. Although this did not occur with ERPs, our oscillatory EEG data showed some differences to those described earlier. In this experiment oscillatory activity to real faces and line faces showed changes only in the gamma range at similar time points around the 200–300 ms post-gaze change time range. These patterns of activity were quite different to control motion stimulation with changes in beta and gamma activity occurring at different time points relative to changes observed with faces (Rossi et al., 2015). It is possible that the differences in oscillatory profiles of activity across the two experiments were driven by the different task requirements: a color change detection task with required response on each trial, as opposed to the detection of an infrequent target stimulus consisting of a photonegative of any presented stimulus type. The other possibility is that the context in which the stimulus was presented may have affected the type of elicited neurophysiological activity. At this point in time we cannot distinguish between these two possibilities. Having said that, there is a clear difference in the behavior of ERP activity (phase-locked to the stimulus and hence visible in an averaged ERP) relative to oscillatory EEG activity (not necessarily be phase-locked to stimulus delivery, but still elicited to the gaze change). From our studies with line-drawn faces it is clear that context/task does *not* influence *N170 ERP* activity, but that is not the case for oscillatory EEG activity, at least when the brain is working in Default mode.

Amygdala activity is impossible to detect with scalp EEG. It is also difficult to detect with MEG sensors (with the ability to detect activity in deep sources depending in part on detector type and sensitivity). On occasions, intracranial recording electrodes for seizure detection are implanted in this region. In a study on six epilepsy surgery patients, Sato et al. (2011) reported on changes in oscillatory EEG activity to viewing gaze and control stimuli changes and also changes in control stimuli. Patients viewed isolated eye stimuli that changed their gaze position and were required to respond infrequent change in color of a centrally presented fixation cross on a white background that occurred between presented eye stimuli. Oscillatory EEG activity in the range 4–60 Hz was examined, and statistical testing revealed a significant differential broadband gamma burst of activity that occurred at around 200 ms after the gaze transition when the eye conditions were compared with the control (dynamic mosaics) (Sato et al., 2011). Unfortunately, ERP activity was not evaluated in this study. It would be interesting to see if parallel changes in ERP activity *and* gamma activity would have been observed, as was seen in the study by Caruana et al. (2014).

At this very early stage of investigation of oscillatory EEG/MEG activity elicited to gaze/social attention changes, it appears that gamma activity may play an important role in processing this important visual stimulus. The intracranial investigations indicate that gamma activity is augmented in the lateral temporal cortex to gaze aversion (Caruana et al., 2014) and that this type of activity is clearly larger than that observed to non-eye/face controls (Sato et al., 2011) in nonsocial tasks. Also, in nonsocial tasks, changes in gamma activity recorded in scalp EEG are also affected by type of gaze transition. What remains unknown at this point in time is how social versus nonsocial judgments are likely to influence elicited gamma activity, and how also experimental context modulates these data. Unfortunately, scalp EEG studies cannot reliably record higher frequency gamma activity, because of the low-pass filtering effects of the skull (Srinivasan, Nunez, Tucker, Silberstein, & Cadusch, 1996). Hence, more intracranial EEG studies and perhaps MEG studies will be required to gain a better understanding of the functional significance of these changes in high-frequency oscillatory activity.

Using an interaction task between two individuals, Iwaki (2013) recorded MEG activity in a subject as they observed another and altered their gaze relative to the eye movements of the observed individual every couple of seconds. Direct and averted gaze were alternated. Interestingly, significant changes in MEG activity in response to viewing direct versus averted gaze were seen in the gamma range (35–45 Hz) at a large number of MEG sensors that were located over bilateral aspects of the posterior temporal, parietal, and frontal aspects of the head. These effects occurred at isolated intervals during the 2 s recording epoch (Iwaki, 2013). In this study only one subject was studied at a time, and it may be that the presence of a real (live) person might have driven these effects—as found by Ponkanen et al. (2008), where the effects of direct gaze produced stronger frontal EEG changes in the alpha band (discussed in the next section).

In a fascinating dual-interactive EEG study, Lachat et al. (2012) recorded scalp EEG from a pair of subjects engaging in a task manipulating gaze direction and joint attention. In an ingenious experimental design, gaze direction was cued by light-emitting diodes (LEDs) in a semi-arc between the two subjects, where one could be also instructed to follow the gaze of the other. In one manipulation of joint attention, one subject would follow the gaze of the other to look at an illuminated LED (whose onset had cued the first subject's gaze transition). A condition in which the subjects both looked at the same LED served as a control—here their gaze was on the same target but had been initiated under different conditions. To examine the effects of gaze direction, subjects could look at different LEDs, but could be cued to this either by the gaze of one of the subject's or alternatively by LED onset. These various conditions resulted in a 2 × 2 design for Joint Attention (present, not present) and Instruction (social—gaze dependent, nonsocial—LED color dependent). The experimenters specifically investigated oscillatory EEG activity in the alpha range across the entire scalp in these experimental manipulations that examine EEG activity during an epoch immediately following each gaze transition. Significant changes in alpha range activity across the left centro-parietal-occipital scalp were noted as a main effect of *joint attention*. No main effect for instruction or interaction effects for joint attention/instruction were documented (Lachat, Hugueville, Lemarechal, Conty, & George, 2012). Activity in other EEG frequency bands was not investigated in this study, so it is not clear how these data fit with the other studies we have discussed.

So far, the existing changes in oscillatory EEG data appear to be somewhat at odds with one another. Investigators have not typically examined the whole EEG frequency range, or the whole scalp, so it is unclear if changes in EEG are spatially localized and confined to a narrow frequency band or are more extensive. Intracranial data show increased gamma to averted gaze at a time period corresponding in time with the occurrence of the N170 (Caruana et al., 2014). Scalp EEG studies show very brief differential gamma effects for direct and averted gaze across the occipitotemporal scalp (Rossi et al., 2015), as well as changes in the beta band (Rossi et al., 2014) and alpha band (Hietanen et al., 2008; Lachat et al., 2012). These varied data indicate a clear need to systematically investigate the oscillatory EEG activity across the entire frequency spectrum in the same subjects under a series of experiments that compare social versus nonsocial judgments, as well as examine potential within-experiment stimulus context effects that might be present. By performing these studies and also examining ERP activity concurrently, a more coherent neurophysiological profile of activity elicited to gaze/social attention changes will emerge. Currently, the functional significance of the observed oscillatory changes with respect to social attention remains unknown.

4.4 Naturalistic Tasks and Ecological Validity of Experimental Stimuli

Ecological validity and stimulus type also need to be considered in tasks evaluating gaze perception and social attention. As noted earlier, most studies have used the onset/offset of static images of full-on gray scale faces whose gaze may appear as direct or averted—a somewhat unrealistic representation relative to what we experience in our daily lives. N170 ERP activity elicited to gaze changes has been found to be significantly larger to gaze changes and eye closure performed by *a real (live) actor*, relative to the face of the same actor presented as a static two-dimensional image in a passive viewing task. Interestingly, however, N170 modulation as a function of gaze was only reported to the real actor and not to the presented video of the same individual. Specifically, the largest N170s were reported to the direct gaze condition (Ponkanen et al., 2011). Hietanen et al. (2008) have also investigated oscillatory EEG changes in the alpha band (8–13 Hz) in a similar passive viewing task. Specifically, an asymmetry in alpha band activity across the frontal scalp occurred for viewing a live actor changing their gaze, and not to viewing images of the same actor performing the same action. Alpha activity was relatively larger in the left relative to the right frontal scalp when direct gaze was viewed, and was larger in the right frontal scalp (relative to left) when averted gaze was viewed. These hemispherically selective changes in frontal EEG asymmetry were interpreted as engaging approach and avoidance systems in the brain, respectively. Additionally, measurements of autonomic activity, as assessed by skin conductance, when the actor directed their gaze at the observer showed greater galvanic skin responses to viewing the actor, and particularly to a direct gaze situation (Hietanen et al., 2008). Increased N170 amplitudes and autonomic responses were attributed to direct gaze being more arousing to the subject (Hietanen et al., 2008; Ponkanen et al., 2008), and potentially being more socially salient. The effects of direct gaze do not appear to be affected by culture: similar effects of direct gaze occur for observers in Western and East Asian cultures (Akechi et al., 2013), despite prolonged direct gaze being regarded as rude behavior in some of these East Asian cultures (Knapp, 1972; Sue and Sue, 1977). Interestingly, individuals from East Asian cultures tend to fixate more on the eyes when making judgments of emotion, as opposed to individuals from Western cultures who show a tendency to focus more on the mouth region (Jack, Blais, Scheepers, Schyns, & Caldara, 2009; Yuki, 2007).

The studies of Ponkanen et al. (2008, 2011) and Hietanen et al. (2008) underscore the need for studies of social attention (and social cognition in general) to use live actors in ecologically valid contexts—the observed experimental effects to viewing real actors in three dimensions are clearly augmented relative to those seen in their two-dimensional image counterparts. Therefore, three-dimensional stimuli might be more likely to elicit significant differences between experimental conditions. Interestingly, the data of Ponkanen et al. did not show differences between gaze conditions for gaze stimuli presented on a monitor, unlike our own multiple studies that demonstrate clear differences between gaze conditions in apparent motion of face stimuli presented on a monitor. Although one can always use task demands and stimulation conditions as a convenient reason to explain divergent findings between different studies, it may well be that monitor refresh rates and resolution/frequency of presented digital video may affect elicited neurophysiological activity, because the gaze transition might not appear as “sharp” or rapid when presented on some monitors. Similarly, gaze transitions generated in an apparent motion paradigm where two successive still images (one with direct gaze and the other with averted gaze) are presented successively may also produce a sharper motion transition than a gaze transition viewed in a real actor. This more instantaneous transition in the apparent motion task might have produced ERPs that are larger and less widely dispersed than those to real motion transition.

Potential differences in the robustness of elicited ERPs to apparent motion versus real video stimulation may be bolstered by our own data: our previous studies using stimuli presented on a monitor have mostly used apparent motion transitions that have shown systematic differences in N170 amplitude between mouth opening and closing conditions (Puce et al., 2000, 2003). We have previously also evaluated ERPs to videos of real mouth motion in a study that also tested the responses to viewing hand and body motion. Notably, although N170 appeared larger for mouth opening movements, the differences between mouth conditions in this study were not significantly different (Wheaton et al., 2001), in videos that were presented at a 30 Hz digitization rate. It could be that videos captured at this rate cannot fully depict the face movement, which is typically rapid, and that this results in an ERP that is not elicited under optimal stimulation conditions. Indeed one could argue that video displays with low refresh rates themselves actually constitute apparent motion stimuli. Future studies comparing real versus video stimulation to different types of facial and bodily movements, as well as video stimulation compared with apparent motion studied in the same experimental session, will be needed to disentangle the effects of these visual stimulation parameters on neurophysiological activity.

Naturalistic experimentation involving multiple subjects engaging in social interactions poses many technical challenges, but in principle, could be studied using ambulatory EEG recordings (Gramann et al., 2011; Sipp, Gwin, Makeig, & Ferris, 2013). If artifacts could be reliably detected and removed, then it might be possible to evaluate changes in oscillatory EEG that will occur as an individual approaches another or a facial expression slowly unfolds. Laboratories that have the capability to examine these types of interactions are relatively few (e.g., Lachat et al., 2012; Sipp et al., 2013) but have the potential to evaluate the brain in a situation that is much more ecologically valid than that reported in earlier studies. This would include the ability to record simultaneous EEG from multiple individuals while they engage in a social interaction.

4.5 Joint Attention and Gaze-Cueing Experiments

Very few studies have explicitly manipulated joint attention in the naturalistic manner described earlier (Iwaki, 2013; Lachat et al., 2012). The change in another's social attention is thought to be automatic and reflexive and to reflect a reorienting of attention in space. Therefore, gaze-cueing experiments have been typically used to study processes related to joint attention (Frischen, Bayliss, & Tipper, 2007). These experiments have evolved largely out of Posner-style paradigms (Posner, 1980) that have cued a subject's covert visuospatial attention to a location in space. These studies are beyond the scope of this chapter.

4.6 Some Outstanding Questions

Over the course of the chapter we have alluded to a number of knowledge gaps in the social attention area. The largest gaps to be filled, in our opinion, are listed below:

How does the functional connectivity of activity elicited in the four social brain networks change as a function of social context and required behavior in tasks investigating social attention? Which networks (and brain structures) are critical to this process, and drive other parts of the network?

How does ERP activity relate to oscillatory EEG/MEG changes in social attention tasks?

What is the functional significance of oscillatory EEG/MEG changes in social attention tasks, and how does this relate to proposed roles for different types of oscillatory EEG/MEG activity changes in other perceptual/cognitive/affective manipulations?

Related to our proposed dual processing mode for social information in the brain (Default/Socially Aware):

Are there consistent neurophysiological correlates of these two states (in both ERP and oscillatory EEG activity)?

Are these two modes associated with different profiles of functional connectivity in the brain's social networks?

The discussion in this chapter has related only to the healthy human brain: Are these two information-processing modes affected to different extents in social cognition disorders?

4.7 Conclusions

Given the above outstanding questions, there is clearly a lot of work to be performed in generating a more complete understanding of the neural processes underlying the evaluation of social/joint attention in the healthy adult brain. The use of multiple assessment methods and the search for converging evidence across EEG/MEG, functional MRI, neuropsychological lesion studies, as well as studies of structural connectivity will be required to disentangle a number of different issues in social attention. What is known, however, is that the brain has a set of networks, which activate selectively to social stimuli and situations. For social attention, networks such as the mentalizing and amygdala networks are important, with areas of the brain such as the pSTS, amygdala, and FG being particularly important for evaluating another's social attention. Neurophysiologically, it is clear that at around a fifth of a second (at around 200 ms), a social attention stimulus is differentiated by the brain, with subsequent neural activity being modulated by the social context of the social attention stimulus. An emerging set of studies have indicated that the use of live human models and naturalistic stimulation will enhance and change the neural activity that is elicited to social stimuli, stressing the importance of using ecologically valid stimuli to evaluate the neural basis of human social interactions. Nonetheless, static images and dynamic videos depicting eye gaze and mouth movements will continue to be used when using live actors is not methodologically feasible.

On the basis of our neurophysiological investigations, we propose a model in which incoming social information can be processed by one of the two modes: a "Default" (or nonsocial) mode and a "Socially Aware" mode. The latter mode is active when making explicit social judgments, whereas the former will be active in most other contexts. Rapid switching from one mode to the other can occur by way of either top-down or bottom-up mechanisms. The nature of this switching and characteristics of each mode remain to be clarified by future studies, which will require the use of both naturalistic stimulation and more controlled laboratory studies, as well as first- and third-person contexts.

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Chapter 5
Social Attention, Social Presence, and the Dual Function of Gaze

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5.1 Philosophy of Traditional Attention Research

The starting point in this chapter is a profoundly important problem that continues to compromise meaningful progress in the fields of human cognition and cognitive neuroscience in general, and human attention in particular. The issue stems directly from the research methods that served experimental psychology so very well approximately a half-century ago. The research philosophy then, and now, centers on the *belief* that to understand how cognition operates in everyday settings, one must first uncover the basic processes and mechanisms that support those operations. This philosophy is grounded on two critical assumptions: The first assumption is that basic mechanisms that subserve cognitive processes are *stable across situations*. The second is that the role of these stable operations can best be revealed and isolated by imposing *rigorous control* over both stimuli and behavior. Together, these assumptions have justified—and even necessitated—studying human cognition and behavior in extremely controlled, simplified, and artificially contrived laboratory paradigms.

In the field of human attention, there are a handful of core paradigms—attentional cueing and visual search are by far the most popular—and these in turn have given birth to attentional phenomena such as attentional capture, the

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attentional blink, and inhibition of return, to name just three. As noted by Kingstone, Smilek, Ristic, Friesen, and Eastwood (2003) and Kingstone, Smilek, and Eastwood (2008) it has become clear that most statements derived from these paradigms are true if, and only if, particular laboratory conditions are met. In other words, the relationship between factor A and factor B is predictable if, and only if, specific conditions are established within the laboratory; the relationship between factors becomes unpredictable when these laboratory situations are not met. Thus, for example, attention experiments have discovered that what people respond to most quickly depends on factors such as (a) what stimuli they might receive; (b) what stimuli they expect to receive; (c) what responses they might execute; (d) what responses they expected to execute; (e) how bright or dim the stimuli are in the environment; (f) how similar the stimuli are to one another; (g) where those stimuli are positioned; (h) how the stimuli appeared in the environment; (i) how long they have been present in the environment; and (j) if the stimuli are relevant to the task at hand, and so on. The take home message is that cognitive processes vary and are affected by what is happening elsewhere within the cognitive system, and therefore cognitive processes depend critically on the specific situational context in which a subject is embedded. Studying individuals in isolation on simple tasks is destined to generate principles of cognition that while internally valid are doomed to fail when they are extended to different situations, especially those that occur during the natural complexities of everyday life.

Kingstone et al. (2003) first took up this argument when they noted that, among other things, the world that people live in is an inherently social one, and that testing people in isolation with simple arbitrary symbolic stimuli is, at best, missing a significant part of the bigger picture, and at worst, getting things altogether wrong. To illustrate this point, they reported that if one merely takes one of the classic attention paradigms, the Posner cueing task (Posner, 1980), and replaces the standard central arrow cue (which points either to the left or to the right) with a schematic face (that looks either to the left or to the right), one produces a very different form of attentional orienting (Fig. 5.1). Critically, and most importantly, the attentional orienting and behavioral outcomes are not predicted, nor explained, by the decades of previous research that used simple nonsocial stimuli as attention cues.

Furthermore, these new social cueing data suggested that the past decades of nonsocial attention research may have been misinterpreted. This possibility was subsequently put to the test, and validated (Ristic & Kingstone, 2006, 2009; Olk, Cameron, & Kingstone, 2008). Specifically, what researchers had thought was a paradigm that isolated volitional attention turns out to be one that triggers a complex interaction between reflexive and volitional attention, an interaction that yields a behavior that bears little similarity to pure volitional orienting. Kingstone et al. (2003) concluded: “Perhaps the most fundamental issue raised by the research discussed here pertains to the validity of laboratory findings in real-world situations. Specifically, the evidence suggests that laboratory studies

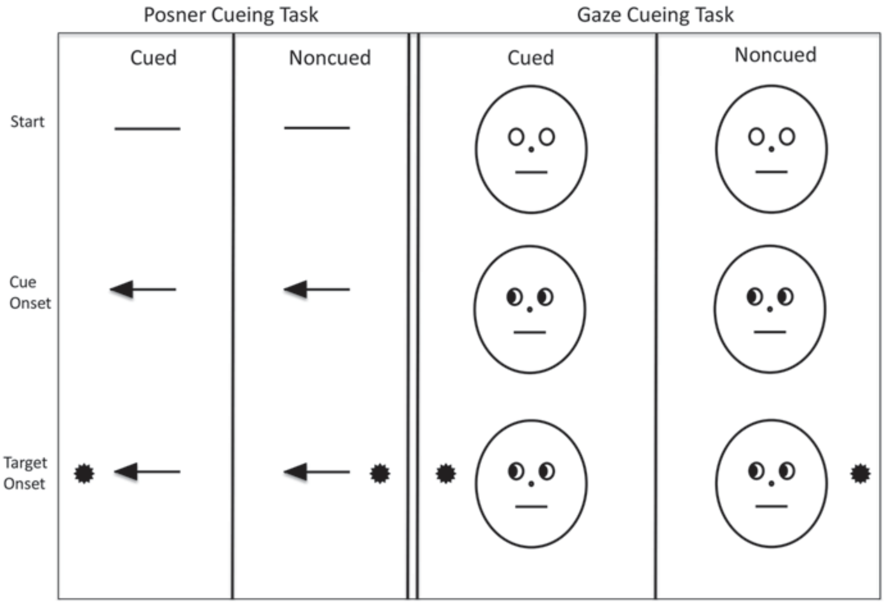

Fig. 5.1 Examples of a Posner cueing task and a Gaze cueing task. Each panel presents three stages of a typical trial: start, cue onset, and target onset. In these examples, the target (a *small black asterisk*) demanding a speeded response appears at either the cued location or the non-cued location

that have lost touch with real-life context may generate fundamental misunderstandings of the principles of human attention and behavior. It would be a [further] mistake to think that our message applies only to the Posner paradigm." (pp. 178–179).

Alas, the irony is that this broader message seems to have been overlooked and what has been latched onto by researchers is that the gaze cueing attention paradigm provides an opportunity to study social attention in the lab. In other words, far from the gaze cueing paradigm bringing into question the external and ecological validity of using simple paradigms to study everyday attention and cognition, it has been taken up by the field as a tool to study real-world attention in the lab (see, e.g., the reviews of Frischen, Bayliss, & Tipper 2007; Birmingham & Kingstone, 2009). For instance, it has been applied extensively to investigate social attention in populations with typical and atypical social development, most notably individuals with autism (e.g., Chawarska, Klin, & Volkmar 2003; Okada et al., 2003; Rutherford & Krysko, 2008; Senju et al., 2004). Contrary to what researchers predicted (but see Ristic & Kingstone, 2005), individuals with autism have not behaved in an atypical manner in the gaze cueing paradigm. This was surprising to researchers because it conflicted with the common everyday experience that individuals with autism fail to spontaneously engage in joint attention behaviors, such as following someone's eye gaze, the way that typically developing individuals do (Baron-Cohen, 1995).

Of course, if the gaze cueing paradigm does not actually tap into real-world social attention then its failure to be sensitive to atypical real-world social attention in individuals with autism should not be surprising at all. In short, the gaze cueing paradigm does not provide a strong measure of real-world social attention. The schematic face that serves as a cue is not real; it has no brain to think with; and the eyes in the face do not actually *see*. And as is outlined in Sect. 5.2, attentional orienting changes dramatically when people are faced with real individuals rather than images of real people.

In summary, attention research has traditionally sought to simplify the issue of investigation by making the experimental context both impoverished and controlled, with the hope of discovering causal relationships between one factor and another. The intention is that by minimizing the complexity of the environment and maximizing experimental control, investigators can create theories that will be universally valid in everyday life. The Posner cueing paradigm is a good example of this approach, as it is one that is so impoverished of social context that merely introducing a face into the paradigm can produce a dramatic change in attentional orienting and behavior. However, the reader should not conclude that the orienting produced by a social gaze cue is yielding results that will scale up to everyday life. The gaze cue only points left and right. It is just a cartoon stand-in for a real person. And as is seen further into this chapter, whether the stimulus is an image of a real person or an actual real person is a very important distinction.

5.2 Cognitive Ethology

It has been proposed both here, and in much greater detail elsewhere (e.g., Kingstone et al., 2008; Risko et al., 2012), that an impoverished highly controlled experimental situation is unlikely to inform the field about cognitive processes as they are expressed in everyday real-life situations. It stands to reason then that by increasing situational complexity and reducing experimental control one will begin to move research in the proper direction, a research approach that Kingstone et al. (2008) called “Cognitive Ethology.” The first very tentative step in this direction occurred about 6 years ago when exploring how individuals look at photos that contain people. While there were a multitude of studies examining how people look at photos of faces that are presented in isolation (e.g., passport-like photos) there were very few studies that examined how people look at photos that contain people as well as a host of other things to be fixated (e.g., chairs, tables, doors, lamps etc.). It was noted that like other researchers who study eye movement behavior, people tend to look at things that they are interested in, and therefore looking behavior can provide a good approximation of a person’s current state of attention (e.g., Findlay & Gilchrist, 2003). And by studying how participants look at people, one can begin to understand the variables that are important to social attention.

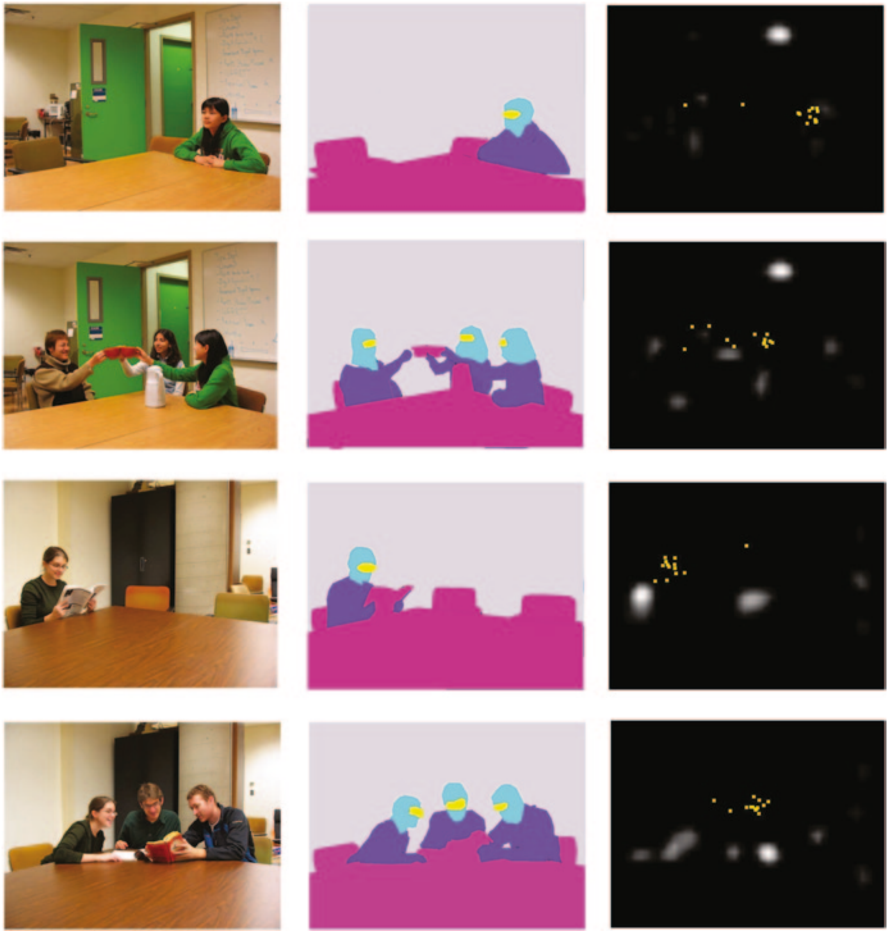

Fig. 5.2 Examples of the scenes used by Birmingham et al. (2009). The general regions are defined (eyes, heads, bodies, foreground objects, and background) and their corresponding saliency maps (*white* areas indicate regions of higher saliency; Itti & Koch, 2000) are overlaid with the first fixations (*yellow points*)

In keeping with the general philosophy of increasing situational complexity and reducing experimental control, people were given a host of different social scenes to look at and giving participants any specific task was avoided. Participants were just told to "look at these photos the way you normally would." The eye-tracking data revealed that people were extraordinarily interested in people, in particular, the eyes of people (Birmingham, Bischof, & Kingstone, 2009; see Fig. 5.2). Furthermore, it did not appear to matter very much where the people were in the scenes, what they were wearing, or even how tiny they were. If there was a person in the scene, then participants were going to look at them, especially their eyes. These results were somewhat surprising because often the eyes in the scenes were very small, and yet, people would quickly, consistently, and repeatedly seek them out. Thus, there seemed to be a profound bias to search out the eyes of individuals in these complex scenes. Moreover, it was subsequently discovered that if participants were given a task to do, such as describe the scenes, or remember the important things in the scenes, then this bias to look at the eyes would often increase relative to other objects in the scene. Indeed, it has proven difficult to find a task that gets people to stop looking at the faces and eyes of the individuals in the scenes (e.g., for difficulty in inhibiting looking at eyes, see Laidlaw, Risko, & Kingstone, 2012). Thus, in a relatively simple task where participants are allowed the "freedom" to look naturally, a robust social attention effect emerges (i.e., a strong bias to look at the eyes of others) that appears to generalize across situations (pictures) and tasks.

It is also noteworthy that, as in the gaze cueing studies above, the addition of a real-world social element into a standard experimental situation (i.e., scene viewing) immediately revealed limitations in the previous foundational work in the field. In this case, it was the prevailing eye movement model of Itti and Koch (2000), which was based on looking behavior in complex scenes that rarely contained people. This model assumes that where participants look in photos is determined by a "winner take all" visual saliency map (e.g., luminance, contrast, color in the scenes), and once the most salient region is fixated, it is inhibited for a period of time and the next eye movement is made to the next most salient region, and so forth. Birmingham et al. (2009) demonstrated that because eyes are small and they are rarely visually salient in complex scenes, the saliency model is incapable of accounting for where participants look in these social scenes (Birmingham et al., 2009; Levy, Foulsham, & Kingstone, 2012). For example, Birmingham et al. (2009), across three experiments, computed saliency maps (Itti & Koch, 2000) for complex real-world social scenes to assess how well saliency predicted where people would look in the scenes. The findings revealed that saliency accounted for *none* of the data. Not only did saliency do no better at predicting first fixations than would be expected by chance (i.e., a random model); Birmingham et al. also found that the saliency associated with where people looked was extraordinarily low. In fact, in one experiment (Experiment 3) observers fixated regions that were actually less salient than would be expected by chance! In addition, the eyes and heads registered at a saliency level of 0. Finally, they discovered that saliency was no more effective at explaining fixation placement for early saccades than for late saccades. In contrast, saccades to the eyes were fast, suggesting a rapid detection of eyes from complex scenes. Thus, visual saliency cannot and did not explain why observers direct their early fixations to the eyes (or heads) of people in scenes. Thus, placing a simple every day social stimuli (i.e., people and their eyes) in a scene seemed to invalidate one of the most successful models of looking behavior.

If saliency is not driving fixations to the eyes of people, then what is responsible for this behavior? In a follow-up study Levy et al. (2012) tested two competing explanations. One was that people were naturally drawn to the eyes of others so that they could assess where they are attending. Indeed, one part of the brain—the superior temporal sulcus—is involved in processing the direction of gaze. The equally plausible alternative was that people were more broadly focused on the faces, and the eyes just happen to be in the middle of the face. Again, there is a specific part of the brain—the fusiform face area—that responds to the sight of faces. To discriminate between these two alternatives, Levy et al. presented observers with images of people and characters from the popular fantasy game "Dungeons and Dragons." The latter consisted of "humanoids" (nonhuman creatures with eyes in the middle of their faces) and "monsters" (bizarre-looking fabrications with eyes positioned elsewhere). The eye movement recordings showed that when participants looked at drawings of humans or humanoids (monsters with more or less human shapes), their eyes moved to the center of the screen, and then straight up to the head and eyes. If the volunteers saw monsters with displaced eyes, then they stared at the center, and then off in various directions to look at the eyes. In short, there was a profound bias toward looking early and often at the eyes of humans, humanoids, and even the monsters. In the latter case, this demonstrates that individuals are biased to pay attention to the eyes of others, and not just the middle of their heads.

The research conducted using social scenes, of course, pertains to simple static scenes (i.e., photographs) of people. In real life people move about, they look at each other, and they talk to one another. What happens in such a situation? Foulsham, Cheng, Tracy, Henrich, and Kingstone (2010) asked precisely this question. In their study participants watched videos of different groups of three individuals sitting around a table discussing a hypothetical situation regarding the most important items that they would take to the moon while having their eye movements tracked. Foulsham et al. (2010) found that despite the fact that the individuals in these videos moved, talked, and interacted with one another, there remained a tremendous consistency in the participants' looking behavior. Specifically, participants fixated primarily on the eyes of the people in the video (see also Cheng, Tracey, Foulsham, Kingstone, & Henrich 2013). Thus, even in this dynamic social context, participants' looking behavior evidenced a clear bias to attend to the eyes of others. Furthermore, as with Birmingham et al. (2009), these findings cannot be explained in terms of basic low-level stimulus saliency, in this case, features like visual motion and sound onsets. Foulsham and Sanderson (2013) and Coutrot and Guyader (2014) investigated whether looks to the faces and eyes of individuals engaged in conversation were significantly affected by changes in visual saliency, or whether the audio is present or absent. In both studies, participants again view complex, dynamic scenes featuring conversation while their eye movements were recorded. Their results indicated that the addition of an audio track increased looks to the faces and eyes of the talkers, and also resulted in greater synchrony for when the observers looked at the speakers (Foulsham & Sanderson, 2013). Critically, however, whether sound was present or not, and independent of changes in low-level visual saliency (Coutrot & Guyader, 2014), people spent most of their time looking at the faces and eyes of the individuals in the videos.

To summarize, it has been found that attention paradigms that are conducted in isolation using simple stimuli cannot predict how people will behave when social stimuli are introduced into an experimental situation. This was initially demonstrated with the gaze cueing paradigm, although the effects there are relatively small and do not provide a very strong instance of social attention. This might be because the cueing paradigm is designed to be very simple (the cue is an arrow or schematic face, the target is an asterisk), highly controlled (e.g., participants typically are not allowed to move their eyes and they can only respond by pressing a button). In contrast, when participants were shown photos containing people the task became more varied (the pictures were all different) and the behavior far less constrained (participants were free to look wherever they wished). Remarkably, and contrary to the classic approach to simplify and control, in this more varied and less controlled setting (i.e., a more cognitive ethological approach) the social attention effects became larger and more robust. Participants primarily look at the people in the scenes, especially the eyes. These findings persisted when stimulus complexity was further increased by introducing videos that involved people moving and talking. Finally, these data provided a strong test of, and invalidated, the prevailing saliency model of human looking behavior.

Based on the collective data presented here, it would seem that the preferential bias to attend to the eyes of others generalizes across levels of complexity. This kind of generalization is impressive. The strong implication from this is that what is being found in the laboratory for static and dynamic scenes will also occur in real life with real people. As will be seen next, it is not quite so straightforward as that. Within a more social context of attention research different subtleties at play are found, and in order to understand why and how that is, the following section delves deeper into the findings of related research. There is slightly greater detail than has been covered thus far by looking at social attention research that goes beyond the confines of the laboratory, fleshing out the implications of such findings and building toward bridging our knowledge between the laboratory and real life.

5.3 Real-World Attention

In recent investigations, researchers have begun to explore looking behavior in real social settings (i.e., with real others present) with an eye toward comparing this behavior to that found in situations that relied solely on putatively equivalent social stimuli (i.e., pictures of people). In an initial study, Foulsham, Walker and Kingstone (2011) put a mobile eye tracker on participants, which captures the eye movements of the wearer but also the records the scene. Participants were given $5, and asked to walk to a cafe on the other side of campus and treat themselves to a purchase, and then walk back to the laboratory. They later had participants watch videos of the campus walks. In this way they could compare where participants looked when they were actually walking across campus to where participants looked when they were watching a video of a walk. Based on previous results in more contrived examinations of social attention, the strong prediction is that participants will look at the eyes of the people on campus in the same way, whether

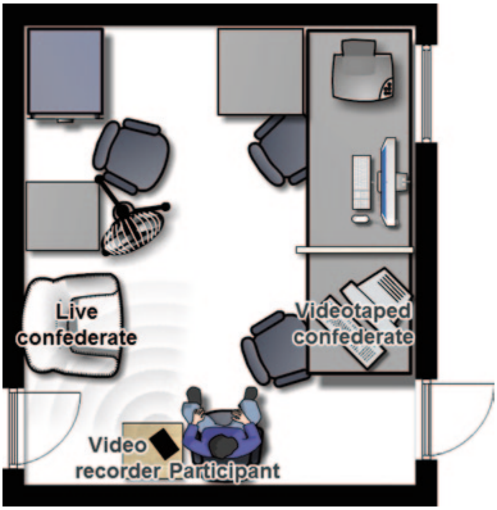

Fig. 5.3 Experimental setup from Laidlaw et al. (2011). Participants sat in the *middle* of the room wearing an eye tracker while either a confederate sat to their *left* or a videotape of the same confederate played to their *right*

the participant is embedded in the real situation or viewing a video. This is not exactly what Foulsham et al. (2011) discovered. While they did find that participants looked at the faces of people both in real life and on video, the timing of those looks differed across the two situations. Specifically, in real life, participants looked at the people who were walking toward them when those people were quite far away. But as a pedestrian moved closer to a participant, the participant would look away from the pedestrian. In contrast, participants watching a video looked at pedestrians when they were at a distance and then as the pedestrian grew closer, rather than look away, the participant was all too willing to continue to stare at the pedestrian's face and eyes as they approached and walked past. Thus it appeared that in real life there was a tendency to *avoid* looking at a stranger when they are close-by, a tendency that is not found when watching strangers on video. Thus, although the stimulus (a pedestrian walking toward the participant) is superficially similar in both cases, when the pedestrian is physically present and is capable of interacting with the participant, the behavior of the participant changes dramatically.

In a more direct examination of the potential differences in attending to images of people versus real people, Laidlaw, Foulsham, Kuhn and Kingstone (2011) measured participants' looking behavior as they were sitting in a waiting room, either in the presence of a confederate posing as another research participant, or in the presence of a videotape of the same confederate (see Fig. 5.3). In this case the potential for social interaction existed only when the confederate was physically present. Participants waited in a room for about 2 min, under the guise that the experimenter had stepped out to collect materials necessary for the study to begin. In this way, participants were unaware that the 2-min waiting period was part of the experiment. In the room, there was either a confederate sitting to their left, quietly completing a questionnaire, or a video of the same confederate from a different session playing on a computer screen to the participants' right-hand side. The computer station was set up to look as though a research assistant had left the video playing and stepped out of the room. Participants' eye movements were coded for looks to the confederate (either videotaped or live; coded for looks to the upper body only), or to the baseline object (for those watching the video, baseline was the empty chair that the live confederate would have sat in during the alternate condition; for those in the room with the confederate, baseline was the blank computer screen that would play the video for other participants).

The prediction, based on the earlier research demonstrating a strong bias to look at the eyes of others (e.g., Birmingham et al., 2009), is seemingly straightforward. There should be a bias to look at the people in the room and, assuming the biases identified in the social scene viewing studies generalizes to actual social settings, there should be no reason to expect a difference between looks to the real confederate and looks to the video of that confederate. The Laidlaw et al. (2011) results demonstrated that although participants frequently looked at the videotaped confederate, they seldom turned toward or looked at the live confederate and in fact, relative to baseline, they were biased *not* to look at the real confederate. This is precisely the *opposite* behavior that researchers have observed for images of people—where participants are preferentially biased to look at the faces of people when they are represented in images (e.g., Birmingham et al., 2009; Levy, Foulsham, & Kingstone 2012). In sum, the Laidlaw et al. (2011) and Foulsham et al. (2011) data demonstrate that the mere opportunity for social interaction—which emerges in a real-life situation—can profoundly alter social attention, with participants being biased away from looking at a real person.

Converging evidence for this conclusion comes from a study using naturalistic observation. Gallup et al. (2012a) placed an object in a busy hallway and monitored individual's gaze behavior with a hidden camera. The researchers were interested in the extent to which pedestrians would be influenced by the gaze direction of other pedestrians (i.e., gaze following). Recall that in the laboratory-based gaze cueing studies, individuals show a strong bias to follow the gaze of a schematic face presented on a screen as evidenced by faster response time and higher accuracy on valid trials (i.e., target appears in the gazed at location) than invalid trials (i.e., target appears in a non-gazed at location; Friesen & Kingstone, 1998; Kingstone et al., 2003). Consistent with this observation, Gallup et al. (2012a) found that overall looks toward the object increased when other pedestrians looked toward the object. Interestingly, this depended on which way the "participant" was facing. When the participant was behind the pedestrian, looks to the object increased when the pedestrian looked toward the object. However, when the participant was facing the pedestrian who gazed at the object participants were actually less likely to look at the object than if no one had looked at the object (i.e., the baseline condition). Thus, the gaze of an oncoming pedestrian directed toward a nearby object appeared to reduce the likelihood of another pedestrian directing their gaze to that object. Again, this behavior is the opposite of what one would expect given the repeated demonstrations in the laboratory that individuals have a strong tendency to follow the gaze of others in a face-to-face situation (e.g., as suggested by the gaze cueing paradigm; Friesen & Kingstone, 1998; Kingstone et al., 2003).

5.3.1 The Duality of Gaze

The Foulsham, Laidlaw, and Gallup work indicates that two fundamental social attention behaviors, gaze selection and gaze following, are altered profoundly when a participant is embedded in a naturalistic context with real people serving as the stimuli. Indeed, the laboratory-based effects appear to reverse their direction in the real world. The working hypothesis to account for these findings is that the act of looking at the eyes of another person in real life communicates information to that person, and that people are acutely aware of the dual function of their gaze, both as a way of collecting information and transmitting it. In short, in real life, attention to another person is a two-way street. But when viewing static images or prerecorded videos of people, there is no communication—observers can channel the information in but nothing is signaled out. As a result of this awareness, in real life observers may choose to reduce gaze selection and gaze following (e.g., civil inattention; Goffman, 1963; Argyle & Cook, 1976), not necessarily because there is no bias to attend to real people, but because they weigh the potential gain of attending with the possible cost of revealing their own attentional state. This idea was best articulated in the early work on gaze by Michael Argyle, "Whenever organisms use vision, the eyes become signals as well as channels" (p. xi; Argyle & Cook, 1976). Interestingly, Argyle and Cook (1976) in making this point were arguing against a prevailing emphasis on considering the eyes only as signals. The situation here among social attention researchers seems to be the opposite in the sense of an overemphasis on the eyes as a channel, as an accumulator of information in the world, and ignoring the eyes as a signal. Thus, again a rapprochement between these two views of gaze is encouraged. If social attention is to be understood, gaze must be considered as both a signal and a channel (see Freeth, Foulsham, & Kingstone, 2013; Wu, Bischof, & Kingstone 2013, 2014, for three recent efforts). This dual function framework for understanding social attention places the presence of receptive others in a central position with respect to controlling where people attend. This idea (i.e., the presence of others changes where one attends) beckons the need for research on social attention (typically conducted by cognitive psychologists) to be integrated with the long and venerable history of research on social presence (typically conducted by social psychologists). To this end in the following we move away from what has predominantly been a focus on our own work (though with many exceptions of course) and provide a brief review of research on social presence, before returning again to some recent work of ours investigating the influence of social presence on gaze.

5.4 Social Presence

Investigations into the effects of social presence are said to be one of the oldest forms of research in social psychology (Zajonc, 1965). While first documented by Triplett in the late nineteenth century, interest in such effects were largely ignored until Zajonc's (1965) seminal review of "social facilitation" brought them back into the social psychologist's spotlight. There are, of course, myriad of ways in which the presence of one person might influence another, but for our current purposes we will focus on what is referred to as "audience effects" or "mere presence." As defined by Guerin (1986), mere presence effects refer to the influence of another person when all other influence has been removed except the physical presence of another.

5.4.1 The Influence of Social Presence on Performance

Early research on presence effects generally found facilitatory effects of the presence of others. For example, Travis (1925) demonstrated that individuals were more accurate in a motor task in the presence of others (see also Bergum & Lehr, 1963). In addition, researchers found improved performance in cognitive tasks, for example, when given simple math problems and word association tasks, people would perform better when another person was present (Dashiell, 1930). As research progressed, demonstrations of inhibitory effects of the presence of others started to emerge (i.e., decreased performance in certain tasks when others where present; e.g., Pessin & Husband, 1933). These findings led to the influential idea that the presence of others facilitates performance of learned responses, but inhibits the acquisition of new knowledge (Zajonc, 1965). In a massive meta-analysis of 241 studies combining the results of nearly 24,000 participants (all studies done before 1982), the idea that the effect of social presence depends on the type of task (i.e., for complex tasks there is a negative effect of social presence, whereas with simple tasks there is a positive effect) was seemingly confirmed (Bond & Titus, 1983).

The Bond and Titus (1983) review also addressed the prevailing hypotheses regarding the mechanism(s) underlying social presence effects at the time. The strongest contenders were that the effects were due to (a) evaluation apprehension and self-presentation (i.e., regulation of public image; Bond, 1982; Geen, 1985), (b) an overall general drive or increased alertness/arousal (i.e., energization of dominant/learned responses; Zajonc, 1965), or (c) factors relating to objective self-awareness (i.e., regulation of ideals of the self and actual performance; Carver & Scheier, 1981). In a subsequent review by Guerin (1986), which was more stringent in the selection criteria it applied (i.e., it focused on mere presence), a robust social presence effect was found in the majority of the experiments, as long as the observer that was present was able to engage in the evaluation of the participant (e.g., rather than being busy with a non-related task or unable to actively observe the participant). Guerin (1986) concluded that the presence of another person increased one's likelihood of conforming to a public norm. At this point in the field, social presence effects were a well-established finding, and although there was still disagreement as to the underlying mechanism, it was accepted that arousal offered a poor account of the data and the opportunity to evaluate the participant was an important contributing factor to social presence effects.

5.4.2 The Influence of Social Presence on Overt Behavior

While much of the early work on social presence effects focused on its influence on performance in relatively simple tasks, a related line of research emerged focusing on the influence of social presence on more complex behaviors. One of the central ideas driving this line of research is that the presence of others increases conformance to social norms (Guerin, 1986). Early work demonstrated, for example, that when participants were asked to sort materials with erotic visuals, they would spend less time doing so when in the presence of others versus when they were alone (Weiss, Miller, Langan, & Cecil, 1971). Children listening (on headphones) to an amusing story would laugh more when someone was present in the room than when they listened to the same story alone (Chapman, 1973), and individuals would increase the size of their donations if they knew they could be seen by others (Satow, 1975). Indeed, this latter effect has even been documented in children as young as 5 years old, where these children were given stickers and asked to share these stickers with another child. In the conditions where their actions were visible to another person, children were more likely to share their stickers establishing that even children at a young age are much more likely to be generous and act in a more prosocial way when there is an audience (Leimgruber, Shaw, Santos, & Olson, 2012). Indeed, examples of such effects abound. In the following we describe a few sets of studies documenting important moderators of these social presence effects and discuss briefly proposed mechanisms.

There exist a number of demonstrations of individual difference measures that moderate the influence of social presence effects. Herman, Roth, and Polivy (2003) demonstrated that people will decrease their food intake in the presence of others when the prevalent norm is to eat less, whereas in situations where eating more is expected and signaled, individuals will increase their food intake. Critically, they also found that this influence of social presence on food intake was related to individual differences in impression management, with people rated higher on impression management being more likely to conform to the cued norm in a social setting (Herman et al., 2003). Similarly, Ratner and Kahn (2002) found that people increased the variety of items they consumed when other individuals could observe their consumption choices. Interestingly, this effect was strong enough that when the participants under observation were asked to choose a candy to eat, they would give up selecting their preferred candy in order to select a broader range of items to signal variety in their consumption. Critically, Ratner and Kahn (2002) further found that this "variety effect" was stronger in those who rate higher on a self-monitoring scale. That is, individuals who more frequently regulate their behavior as a function of the situation are more likely to modify their consumption behavior in response to the presence of others. Finally, in an extension of the research on social presence and charity, White and Peloza (2009) demonstrated that the influence of private versus public donation was related to individual differences in impression management. Together these and related findings are consistent with the general notion that the presence of other's increases conformance to social norms in the sense that individuals more likely to engage in acts of impression management are more likely to be influenced by the presence of others (i.e., the behavior change in response to the presence of another person can be seen as a form of impression management).

Another important moderator of social presence effects is familiarity. Much work establishing this link has been conducted in the consumer behavior arena. Dahl, Manchanda, and Argo (2001) investigated how a social presence influences a typically embarrassing product purchase (i.e., the act of buying a condom) where social presence is the source of embarrassment for the consumer. Participants were given money and sent to a pharmacy to purchase condoms. Physical social presence was manipulated by use of a trained confederate either present next to the condom display or not present in the control version of the procedure. Participants were given money to go purchase the product then returned to the experimenter to fill out questionnaires including a Likert scale of how embarrassed they felt during the purchasing task, and an index of how familiar they were with condom purchases. Participants reported significantly less embarrassment in the no presence condition when compared to the presence condition, but embarrassment was felt much more by those who were not familiar with condom purchases. The results point to familiarity with the purchase type acting as a moderator of the social presence effect. Familiarity was hypothesized to result in greater automaticity with the purchase task and is hypothesized to reduce cognitive activity at the point of product selection (Alba & Hutchinson, 1987) and in order to be embarrassed one needs to care about the evaluating social audience (Schlenker & Leary, 1982).

In a similar vein, Ashworth, Darke, and Schaller (2005) tested whether the relation between the individuals and the social presence moderated the social presence effect on coupon use. Using a scenario based paradigm, Ashworth et al. (2005) demonstrated that people were more likely to report using a coupon if they were paying a bill when another person was not present when compared to participants given the scenario where at the time of payment others were present (i.e., a social presence effect). They suggested that participants were more likely to redeem coupons in private versus public situations because in the latter situation coupon use leads to impressions of cheapness. Critically, participants also reported being more likely to use a coupon in the presence of an established friend than a romantic partner, because they viewed it as less important to make a positive impression in the former case. Luo (2005) found a similar pattern in the context of impulsive purchasing (i.e., loss of one's self-control or the surrender to temptation in making a purchase). Specifically, Luo (2005) reported that the presence of family members decreased impulsive purchases, whereas the presence of peers increased impulse buys. Luo (2005) explained this finding by arguing that peers are more likely to reward spontaneity and so impulsivity becomes more socially desirable, whereas family members might be more likely to have economic concerns such as wasting money or be more likely to bring out feelings of responsibility to others, making impulsive behavior undesirable. Thus, the normative expectations of those "others" alter the form of the social presence effect on purchasing behavior. Thus, both the familiarity of the act and the relation between the actor and the "social presence" can influence how the presence of others influences one's behavior.

The last two influences of social presence effects to be discussed are the size of the social presence (i.e., the number of people present) and its proximity. Both of these factors, according to Latane's (1981) Social Impact Theory, should modulate "social strength" and as such the influence of social presence on behavior. Argo, Dahl and Manchanda, (2005) investigated how a consumer would change their behavior if someone was physically present in an aisle where the individual is making a purchase. In their first experiment, participants went to an actual store where they were asked to make a purchase of batteries. A confederate in the store, a few aisles away, would observe the participant and document any self-presentation behaviors, such as the extent of the participant's interaction with the display of batteries, as well as the number of people in the aisle. Results demonstrated that participants would purchase the highest quality brand and spend the most money when others were present in the aisle. Interestingly, they found that while the number of people in the aisle influenced consumer's emotions (in particular annoyance, self-consciousness, confidence, and happiness), it did not change how participants engaged with the display or their brand choice (inconsistent with Social Impact Theory). In a follow-up study, a camera was used to record the participant's activity in order to provide an accurate measure of proximity of other shoppers to the participant in the aisle. Results demonstrated that the influence of social presence was greater the nearer the "presence" was to the participant. In another study of social presence that could arguably be interpreted in the same "social strength" framework, Walker, Risko, and Kingstone (2014) demonstrated that individuals used more fillers ("um" and "uh") during a question and answer task when they were asked questions by a human (and who was therefore present in the room with them) relative to when they were asked questions by a computer. Critically, this difference persisted, but was reduced, when another person was "merely present" in the room. Thus, use of fillers (argued to be a "face saving" act; Smith & Clark, 1993) increases as the immediacy of the social interaction increases (e.g., answering questions posed by a person > answering questions with a person present > answering questions alone). Thus, the Argo et al. (2005) and Walker et al. (2014) works provide some evidence that Latane's (1981) notions of social strength modulate the influence of social presence on behavior.

In sum, the mechanisms underlying individuals increased conformance to social norms in the presence of others is still a matter of some debate. Baumeister (1982) suggested that self-presentation concerns are responsible for the tendency to conform to social norms when in the presence of others. Whereas other researchers suggest that social presence increases self-awareness and this leads to norm conformance (Wickland & Duval, 1971), Carver and Scheier (1981) suggest that it activates efforts to reduce gaps between an internal social norm people hold, the behavior someone wants to display, and the present behavior that is being performed. Part of the problem in distinguishing between these mechanisms is that the different accounts tend to make similar predictions (Guerin, 1986). For example, in keeping with the self-presentation and self-awareness accounts, it would be expected that individual differences in impression management would moderate the effect of social presence on prosocial behaviors as demonstrated above. Nonetheless, understanding the mechanisms underlying social presence effects remains an important goal for research in this area.

5.4.3 Implied Social Presence

As reviewed above, the actual physical presence of another individual can have profound effects on performance and behavior in rather complex settings. Interestingly, the physical presence of another person is not absolutely necessary for such effects, rather a simple reminder or cue (e.g., a camera) that one might be watched can induce effects similar to when someone is actually present (Bateson, Nettle, & Roberts, 2006). Indeed, Latane (1981) suggests that all social forces stem from real, implied, or the imagined presence or actions of others. In the following, we briefly review research on implied social presence effects before turning back to the influence of social presence on attention.

The earliest work that directly investigated implied social presence effects was documented by Putz (1975). Putz examined responses to a low complexity task under different supervision situations: direct supervision by an individual, closed-circuit television (CCTV) recording, a one-way window, and a no supervision condition. His findings demonstrated that participants performed better on the cognitive task under all of the three supervision conditions with no significant difference between the physical presence condition and the other two implied social presence conditions. This established strong evidence that whether a presence is real or implied, the effect of social presence is robust. Wicklund and Duval (1971) also demonstrated that the presence of a video camera increased participant's performance.

Like work on actual social presence, research has revealed that an implied social presence increases conformance to social norms. For example, Van Rompay, Vonk, and Fransen (2009) demonstrated that people were more likely to help to collect a pile of questionnaires that where dropped by a confederate in a laboratory when there was a security camera in the room, compared to no security camera present. In addition, this effect was moderated by individual differences in social desirability (i.e., those higher in social desirability were more influenced by the presence of a security camera than individuals low in social desirability).

Even more subtle cues of implied presence, such as eye-like images, have also been proven to be sufficient to increase prosocial behavior (Ernest-Jones, Nettle, & Bateson, 2011; Nettle et al., 2013). Bateson et al. (2006) reported that a simple image of a pair of eyes significantly increased donations to an honesty box system meant to collect money for drinks in a shared coffee room. Similar studies have found that people are more likely to clean up cafeteria litter or garbage at a bus stop when eyes are present (Ernest-Jones et al., 2011; Francey & Bergmüller, 2012), and they will even donate more to charities (Nettle et al., 2013; Powell, Roberts, & Nettle 2012). For example, Powell et al. (2012) conducted an 11-week field experiment in a supermarket, where they displayed eye images on charity collection buckets that were set up at the checkout locations. Their results indicated that the presence of eyes increased charitable donations by 48%, relative to the donations to the control buckets with no eye images. The effect of the eye images was much stronger when the supermarket was less busy, an interesting finding that was replicated by other research using eye cues to study prosocial behaviors. Both Ernest-Jones et al. (2011) and Ekström (2012) found that eye images exert the strongest influence on prosocial behavior when there is less of a real social presence. This could be explained by the fact that when there is a real source of presence it "trumps" the influence of the implied presence cues, in this case the images of eyes.

Apart from external cues to being watched, social presence can also be imagined by an individual, in that a person might imagine that someone else is present watching and evaluating them. For example, in Dahl, Manchanda, and Argo (2001) the researchers had an imagined presence version of the condom purchase task. Participants were sent to a condom vending machine within a restroom of a building. They were asked to make the condom purchase and subsequently return to the experimenters. Upon their return, they reported the thoughts and feelings they had experienced during the task and rated their levels of embarrassment related to the purchase. Participants were also asked to identify what caused the feelings they reported, which was coded for mentions of imagining another person, and how familiar they were with the purchase. They found that imagining the presence of others increased participant's ratings of embarrassment, and that familiarity actually reduced the likelihood of imagining an audience (social presence) but did not interact with participant's embarrassment as in the real presence study.

5.4.4 Real Versus Implied Social Presence

Overall the research on the influence of an implied or imagined social presence argues strongly that they might share underlying mechanisms. However, direct comparisons between implied and real social presence are rare (e.g., Putz, 1975), and as such strong claims about similarities and differences between the two are difficult to make at present. Nevertheless, we outline some contrasts in hopes of spurring research into this important issue.

There are clearly many similarities in the effects of actual and implied social presence. Both can improve behavior in simple tasks (Pessin & Husband, 1933; Putz, 1975), both appear to increase conformance to social norms (Baumeister, 1982; Van Rompay, Vonk, & Fransen, 2009), and both are moderated by individual differences in sensitivity to such conformance (e.g., individual differences in impression management; Uziel, 2007). More direct evidence for a shared mechanism can be found in work by Powell et al. (2012; see also Ekström, 2012) where they demonstrated that an implied social presence (eyes) has "less" of an impact relative to the control condition when there was a greater amount of actual social presence (i.e., other people around the checkout). Thus, the two effects clearly are not additive as would be predicted on the account that they reflect two independent effects on behavior. In another direct comparison, Dahl et al. (2001) did find what could be an important difference between the influence of actual and imagined social presence. Specifically, with real presence they found that familiarity with the embarrassing purchase decreased embarrassment, whereas with an implied presence task familiarity did not interact with measures of embarrassment. While it was unclear what could be responsible for the different influence of task familiarity across the different types of social presence, it seems clear that research adopting designs like those in Powell et al. (2012) and Dahl et al. (2001) would help greatly in understanding the mechanisms underlying implied and actual social presence effects.

While actual and implied social presence effects might be similar *qualitatively*, there seems to be an intuitive notion that they might differ *quantitatively*. In particular, an implied source of presence might be viewed as a weaker or more transient effect than a real physical presence. This could be conceptualized theoretically in terms of the "proximity" or "immediacy" of the social presence (as discussed above). For example, one could argue that an implied social presence is not as strong as a real presence, given that implied presence is an indirect source/cue of being monitored. Interestingly, the limited number of direct comparisons does not seem to support this notion. For example, when Putz (1975) compared direct supervision by an individual to CCTV recording there was no difference in the amount of social facilitation relative to baseline. In addition, in Powell et al. (2012) the difference between no eyes and eyes near a donation box had a larger influence on charitable behavior than the number of actual individuals present. Thus, at least with the available evidence (which is not much), the magnitude of actual presence effects does not seem to be larger than the magnitude of implied social presence effects.

5.5 Influence of Social Presence on Gaze

Based on the dual function of gaze notion described above—we use our eyes to collect information and communicate with others—and with the review of social presence effects, it seems reasonable to suggest that the real or implied presence of others might impact our looking behavior. In addition, this influence should take the form of gazing in a manner that conforms more to social norms when in the real or implied presence of another. While the research demonstrating that individuals gaze behavior changes in response to the actual presence of others can be interpreted as consistent with this idea (e.g., Laidlaw et al., 2011; Gallup et al., 2012a), these were not direct tests of the hypothesis that social presence will produce gaze behavior that is more socially normative (i.e., the "social norm" in each case being to some extent unclear a priori). In addition, this work focused on actual presence rather than implied social presence. In the following section we review work directly addressing the hypothesis that an implied social presence increases socially normative looking behavior.

Risko and Kingstone (2011) generated the speculative hypothesis that one's awareness of gaze as a signal, combined with the desire to adhere to social norms, might lead people to change their looking behavior when they are aware that their eyes are being monitored. In other words, they suggested that simply wearing an eye tracker might be sufficient to imply the presence of another individual and alter attention. Eye trackers provide a moment-to-moment record of where an individual is looking and given the importance of the eyes as a communicative tool, it might serve as a particularly powerful form of implied social presence.

To test the idea that wearing an eye tracker might serve as an implied social presence and influence looking behavior, Risko and Kingstone (2011) compared looking behavior when individuals knew their eyes were being watched (via an eye tracker) and when they did not. In all instances, looks were actually recorded using a hidden camera. Participants took part in a natural looking task in which they performed a simple computer task alone in a testing room that contained objects typically found in an office. In addition, Risko and Kingstone mounted a provocative sexy swimsuit calendar in the testing room. After completing the computer task, participants remained alone in the room for a short amount of time. It was participants' looking behavior to the calendar during this free time that was of interest. They predicted that if social presence influences looking behavior, then individuals should alter their behavior to be consistent with social norms when wearing an eye tracker and should be less likely to look at the sexy calendar than individuals not wearing an eye tracker. The results were clearcut. Participants wearing an eye tracker were much less likely to look at a provocative stimulus than individuals not wearing an eye tracker. An additional group who wore the eye tracker but were told it was not recording, behaved based on whether they believed that their eyes were actually being tracked or not: they modified their looking behavior when they still thought their gaze was signaling their attention.

Theoretically, this study suggests that eye trackers can serve as an implied social presence. Whether participants looked at the sexy calendar or not depended on whether they believed that their looking behavior was being monitored. If they felt that their eyes were being watched, they avoided looking at the calendar, in accordance with the prosocial norm that discourages objectifying woman by staring at their bodies. In contrast, if participants felt that their eyes were not being monitored, and therefore their looks at the calendar would not be seen by anyone else, and hence not reflect poorly on them, then they were all too willing to look at the calendar.

Extending this work Nasiopoulos, Risko, Foulsham, & Kingstone (2014) examined the degree to which the implied social presence effect demonstrated by Risko and Kingstone (2011) was sensitive to the extent to which participants were familiar with or had been exposed to the eye tracker. The researchers added an initial sham visual search task to the calendar protocol in Risko and Kingstone (2011) designed to provide participants (in some conditions) with time to "habituate" to the presence of the eye tracker. There were four groups: (1) no eye tracker worn in either the search task or the calendar condition (no eye tracker group); (2) eye tracker worn only in the calendar condition (standard eye tracker group); (3) eye tracker worn for all phases (all phases eye tracker group); and (4) eye tracker for all phases but participants recalibrated between the search and calendar conditions (eye tracker recalibration group). This latter group provided an opportunity to test a specific version of a habituation effect, namely, that the familiarization stage (i.e., the visual search task wearing the eye tracker) has its effect by reducing awareness of the implied presence.

Nasiopoulos et al. (2014) results (see Fig. 5.4) replicated the Risko and Kingstone (2011) implied social presence effect (i.e., those in the no eye tracker group looked more at the provocative calendar than those in the standard eye tracker group). Furthermore, participants in the all phases group looked at the provocative stimulus just as much as the no eye tracker group and significantly more than the standard eye tracker group. Thus, a short familiarization period eliminated the influence of the implied social presence on looking behavior. Finally, participants in the eye tracker recalibration group behaved like those in the standard eye tracker group, namely, they avoided looking at the provocative calendar, just like the standard eye tracker group. This latter result suggests that the familiarization period likely reduced the influence of the implied social presence by reducing awareness of the implied presence. Theoretically, this result has important implications for the dual function framework in that it suggests that the prosocial looking behavior found in both studies likely reflects a controlled or effortful process that requires deliberate monitoring.

While the Risko and Kingstone (2011) and Nasiopoulos et al. (2014) studies clearly demonstrate that what we attend to is influenced by an implied social presence much interesting work remains to be done. Establishing these effects as genuine social presence effects, for example, could be strengthened by demonstrating that individual differences in impression management moderate the influence of wearing an eye tracker on gaze. This work also highlights potential

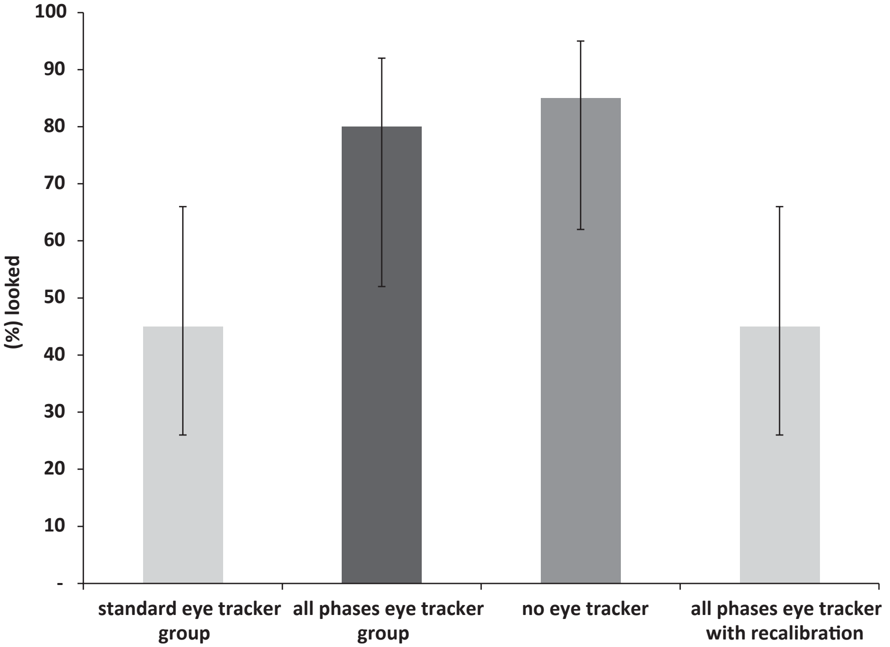

Fig. 5.4 Results from Nasiopoulos et al. (2014). Percentage of participants who looked at the provocative stimulus as a function of condition. See text for details

ways forward with respect to understanding social presence effects in general. For example, with respect to directly comparing actual with implied social presence, the paradigm developed by Risko and Kingstone (2011) could easily be adapted to compare across types of social presence. In addition, the Nasiopoulos et al. (2014) study is, to our knowledge, the first to directly demonstrate a decrease in a social presence effect as a function of length of time the individual is exposed to the presence. This seems a critical demonstration from both a theoretical and a practical point of view. For example, with respect to the latter, it suggests that any prosocial behavior (e.g., CCTV cameras in public spaces) spurred by a social presence might be short-lived. Indeed, this interaction between exposure and presence would be an interesting avenue to pursue with respect to the comparison between actual and implied social presence (i.e., it might be harder to “forget” there is another person present than forget your eyes are being tracked or that there is a camera in the corner of the room).

Methodologically, this research has a number of important implications for the attention researcher (particularly if they are interested in natural looking behavior). For example, it is clear that eye trackers, a favorite of attention researchers, alter looking behavior that could be problematic in a number of scenarios. Importantly, this effect may be minimized through familiarity or exposure but this effect is fragile in the sense that a simple reminder that a person is wearing an eye tracker can switch individuals back to their prosocial looking mode. Another interesting methodological implication of the demonstration of an implied social presence effect in particular is that it may be possible to study social attention in a more socially authentic manner without involving anyone but the participant in the study (i.e., the presence of the other person simply needs to be implied). Obviously, there are some practical attractions to such a situation. For instance, it would mean that a researcher could gain some experimental control without compromising the social authenticity of the situation. More generally, this line of research clearly highlights the utility of applying a dual function perspective on understanding how we attend in social situations.

5.6 From Social Psychology to Cognitive Ethology

The preceding sections support two general ideas that we think are useful to make in the context of the present argument. First, the investigation of social attention would benefit from greater integration of work from social psychology. While this integration might seem obvious, it has not been practiced. This is largely because research on social attention largely grew out of research on basic issues in "nonsocial" attention (e.g., as seen in the transition from the traditional Posner cueing tasks to the gaze cueing tasks popular in social attention research). This integration could consist of adapting well-known social psychological phenomena (e.g., social presence, implied presence effects) into paradigms that afford the evaluation of their attentional manifestations. This integration could also involve a more general sensitivity to the importance of social context (e.g., Argyle & Cook, 1976). For example, this might have made it less surprising that looking behavior would change so profoundly when stimuli change from images of people to real people.

The second idea is that attention research can benefit from considering more closely the importance of social stimuli to the attentional system. As we noted, historically, studies of human attention have been undertaken in sterile laboratory settings, with researchers conducting experiments using simple visual images designed to uncover the putative basic visual features that determine where, and to what, people attend (e.g., abrupt onsets, high contrast stimuli). Kingstone et al. (2003) made the argument that the principles derived from such research will ultimately fail to scale up to the real world because these studies do not take account of the fact that the real world is rich in social meaning, and people care about, and have a preferential bias to attend to, socially relevant information. In other words, the real world is a social world and the social world can profoundly shape attentional behavior. By taking this basic notion into account, one should be able to achieve greater insights into human attention. A clear example of such a potential contribution of social attention to attention research proper was presented earlier in the context of the challenge faced by the dominant saliency-based models of attention in accounting for individual's bias to attend to the eyes. It is likely that more contributions of this kind will be made as social attention research further pushes the boundaries of attention research in cognitive psychology.

Lastly, the research on social attention reviewed here offers important support for the idea that research in cognitive psychology can benefit from taking targeted steps in the direction of better approximating the “real world” in its investigations. In order to better understand how the social world shapes attention, researchers have examined the role that socially relevant stimuli have on the allocation of attention using progressively more natural stimuli and tasks (e.g., from schematic faces to real social interactions). Each step along the way it is safe to say researchers were rewarded for their willingness to give up a bit of control. We find no reason to think this would not be true in other areas of cognitive psychology. The application of a more cognitive ethological approach (see Kingstone, 2009) represents one way to take these steps.

5.6.1 Outstanding Questions

This chapter, particularly the review of the social presence literature, makes clear that there remain a number of interesting questions to answer in terms of how social and implied presence influence attention. One key question concerns the direct comparison of real versus implied social presence effects on attention. Do real people have a greater influence on what we attend to or might the idea of being watched suffice to lead to similar effects? In a similar vein, another important consideration outlined by Latane (1981; see also Argo et al., 2005) is how proximity of the source of presence might influence attention. For example, if an observer is nearby, we might keep our eyes and head oriented away from a provocative stimulus, but if that observer was a little further away (possibly too far away to discriminate where we were looking), then we might keep our head oriented away from the provocative stimulus but let our eyes visit the stimulus. The critical idea here, in the dual function framework, is that for our attentional state to communicate information to others it needs to be “readable” by them. If it were not readable (e.g., because of proximity), then there would seem little motivation to modify our attentional behavior. Another important question to resolve in this domain will be to determine whether the same individual difference variables that influence social presence effects also influence such effects on attention. If the social presence effects reported by Risko and Kingstone (2011) and Nasiopoulos et al. (2014) reflect manifestations of the general class of behavior identified in research on social psychology, then a similar pattern would be expected (e.g., changes in gaze as a function of individual differences in impression management). Confirmation of such a prediction would constitute an important connection between social presence effects in general and social presence effects on eye movements.

5.7 Summary and Conclusions

We have covered a lot of ground in a very short amount of time. We began this chapter by noting that the philosophy of traditional research in human cognition and attention is to simplify and control situational variance in an attempt to uncover principles of attention and behavior that will scale up to the everyday complexities of natural life. By introducing situational complexity via “social” content and loosening experimental control (e.g., free looking monitored by a mobile eye tracker), we found that participants tend to look at people, especially their eyes, and this tendency generalizes from static visual scenes to multisensory video environments. The implication (we thought) was that these effects would continue to generalize to real-world domains (i.e., by loosening some of the constraints and using more representative stimuli we had discovered a kind of “general principle”). However, on this score we were wrong. When the images of people that participants could attend to were replaced by real people, our “general principle” did not appear that general after all. Rather, the strong bias to look at images of people, particularly their eyes, seems specific to the typical laboratory experiment. Once those images are replaced by real people the situation becomes more complex. The key seems to be that in real life people can look back at the participant creating a dynamic cycle of potential communication, where one’s looking behavior signals information to the other who in turn can signal information back (e.g., Argyle & Cook, 1976). Indeed, so powerful is this cycle of communication that it appears that one does not even need a real person to be present; their presence merely needs to be implied. The importance of the “other” to social attention brings to the fore the significance of understanding the interaction between social presence, an area of research with a long history in social psychology and social attention. Bringing these two areas of research together has begun to reveal interesting new insights into both social attention and potentially social presence. Research along these lines and within the dual function framework promises a much more sophisticated understanding of social attention in the future.

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Chapter 6
Early Departures from Normative Processes of Social Engagement in Infants with Autism Spectrum Disorder

Sarah Shultz, Ami Klin and Warren Jones

The ability to successfully navigate social interactions is deeply embedded in one's history of social actions—in the accumulation of a vast number of experiences seeking and acting upon socially relevant information. The experiences themselves, as well as the abilities that result from those experiences, progress in a cyclical, iterative manner, both constrained by and then further constraining the way in which the environment is perceived (Jones & Klin, 2009; von Uexkull 1934). In human infants, these processes begin within the first hours after birth (at least): irrespective of the sensory "domain," social stimuli in the environment are perceived by typically developing infants as relatively more salient than other competing stimuli (e.g., Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000; Bushneil, Sai, & Mullin, 1989; DeCasper & Fifer, 1980; Macfarlane, 1975; Simion, Regolin, & Bulf, 2008; Vouloumanos & Werker, 2007). Thereafter, through ongoing cycles of seeking and acting upon such stimuli, infants transform their understanding of the social world through active engagement (Smith & Gasser, 2005). This spontaneous seeking of and acting upon social information is an adaptive reaction displayed by typically developing children from infancy onward, if not before.

In contrast, the diminished interest in, and attention to, a wide variety of adaptive social stimuli has been identified as a pervasive, early emerging, and enduring feature of autism spectrum disorder (ASD). The diminished salience of social stimuli to individuals with ASD is a marker of social disability (e.g., Jones, Carr & Klin, 2008), but it also exerts a compounding influence on subsequent development as a child with ASD fails to accrue an increasingly longer list of social experiences that would otherwise lay the foundation for typical social development.

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Instead, individuals with ASD often engage with a range of nonsocial, physical stimuli (Kanner, 1943; Klin, Lin, Gorrindo, Ramsay, & Jones, 2009; Langdell, 1978; Shultz, Klin, & Jones, 2011), leading to an accumulation of experiences with "things" rather than people. This process, in turn, leads to atypical developmental profiles of functional brain specialization (Grelotti et al., 2005; Schultz, 2000), as that functional specialization is necessarily shaped through activity-dependent processes (LeDoux, 2003).

While reduced visual attention to social stimuli has been widely reported in children and adults with ASD, less is known about the early divergence of such behaviors in infancy, and even less is known about the impact thereof on subsequent development. In this chapter, we focus primarily on visual attention to the eyes of others as a paradigmatic example of an early emerging foundational social ability, that, when disrupted, is both a marker of emerging social disability and a compounding influence on subsequent development. While attention to eyes is only one of many critical mechanisms of social adaptive action, its phylogenetically conserved nature (Emery, 2000), early onset (Farroni, Csibra, Simion & Johnson, 2002), and foundational role in socialization (Brooks & Meltzoff, 2002; Emery, 2000; Kampe, Frith, Dolan, & Frith, 2001) are particularly well suited to investigations of *when* reduced social engagement is first observed in ASD and *how* such disruptions subsequently impact developmental outcomes.

Section 6.1 reviews the canalizing role of preferential attention to stimuli with social adaptive value, including the eyes of others, in typically developing infants' first months of life. Section 6.2 discusses the relationship between changes in typical infants' preferential attention to the eyes of others, changes in their interactions with conspecifics, and changes in related structural and functional brain maturation. Section 6.3 then reviews what is known about the early development of infants who are later diagnosed with ASD, with a focus on their early departures from normative developmental trajectories of social visual engagement with the eyes of others. Finally, Section 6.4 examines the accumulative consequences of such departures, as children with ASD develop increasingly greater specialization in things other than the social world.

Taken as a whole, this review of typical and atypical processes of social engagement highlights the canalizing role of early experience in child development: success in early social adaptive tasks leads to new social experiences and increasingly refined social abilities, but these iterative processes appear to work in much the same way for atypical social experiences (Jones & Klin, 2009). In the case of infants with ASD, early departures from normative processes of social engagement are likely to have profound and long-term effects on the social and cognitive development of these children (see Fig. 6.1). Whereas typically developing infants show an increase in preferential attention to the eyes of others from 2 until 6 months, infants later diagnosed with ASD show mean decline in eye fixation during this early period (with continuing declines thereafter) (Jones & Klin, 2013). While reduced attention to the eyes of others is not in itself a cause of autism, it does represent a marker of emergent social disability as well as a compounding influence on subsequent social and brain development. By mapping the unfolding of social disability in ASD, we hope to constrain future hypotheses about causal mechanisms underlying the disorder.

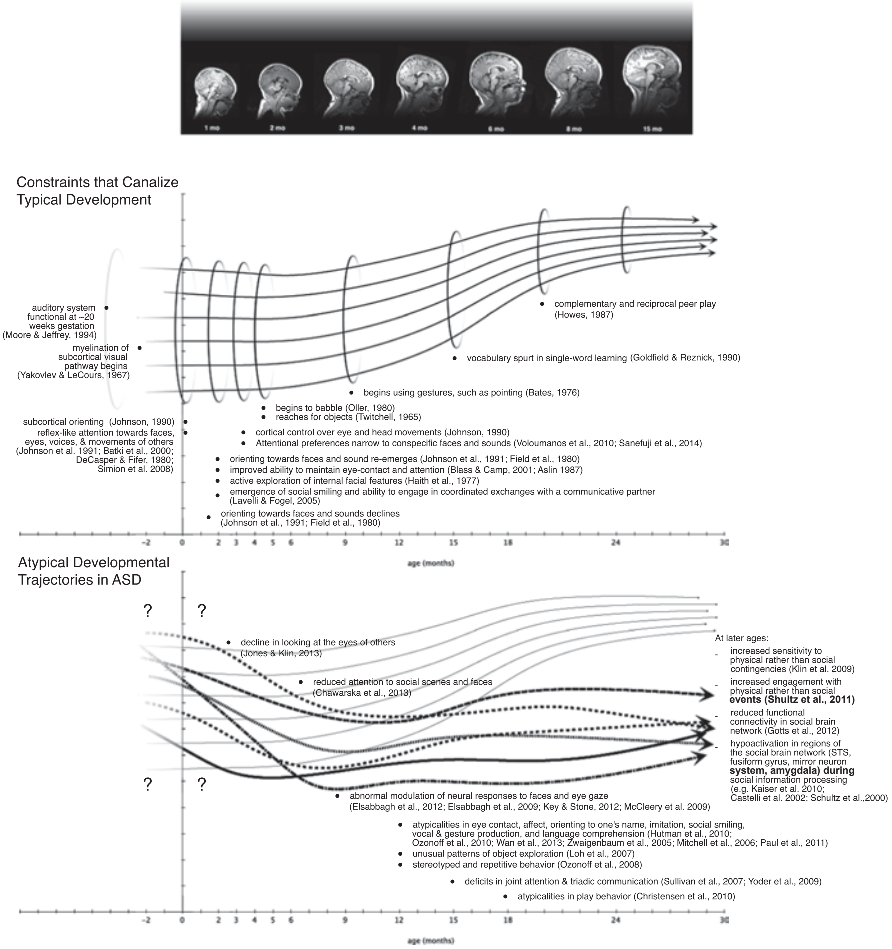

Fig. 6.1 *Summary of some early developmental milestones that serve to canalize and constrain typical social development in brain and behavior.* In typical development *(top panel),* early predispositions and subcortical brain systems guide infants toward what is socially relevant. Seeking social interaction creates further opportunities for social learning and modulates normative brain development. In autism spectrum disorder *(ASD) (bottom panel),* disruption of active seeking of social information alters opportunities for learning; developing brain systems become co-opted in service of alternative goals

6.1 Adaptive Action in Response to Environmental Demands Constrains Typical Development

Given the fragility of human neonates at birth, engagement with a caregiver is the initial task upon which survival depends. Neonates' remarkable attunement to their caregivers, even in the absence of extensive experience with others, presents a ready solution. From the first moments of life, human infants are drawn to the sight, sound, and smell of their caregivers (Bushneil et al., 1989; DeCasper & Fifer, 1980; Macfarlane, 1975). From rooting and sucking reflexes that help breastfed infants find their mother's nipple to preferential attention to conspecifics, neonates display a host of adaptive skills that help them to successfully engage their caregivers (Nagy, 2011). When just 10-min old, infants already show tremendous sensitivity to faces, evinced by their proclivity to track a moving face-like pattern but not a scrambled or inverted face pattern (Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991; Simion, Valenza, Umilta, & Barba, 1998; Valenza, Simion, Cassia, & Umiltà, 1996). By just 5 days, infants demonstrate special sensitivity not just to faces, but specifically to the eyes of another person, preferring to look at faces with eyes open rather than closed (Batki, 2000). Strikingly, and despite rather limited visual acuity (Kellman & Banks, 1998), they are also able, at approximately the same age, to distinguish faces whose gaze is directed toward them rather than away from them (Farroni et al., 2002). These preferences are widespread in other domains as well. Newborns distinguish and prefer their own mother's voice to that of an unknown woman, but prefer the sound of an unknown woman's voice to that of silence (DeCasper & Fifer, 1980). This evidence suggests that typically developing babies have a predisposition to engage with the social aspects of the world around them: the social dimension is most behaviorally salient and what consequently commands the greatest portion of the typically developing infant's attention.

While preferential attention to caregivers has immediate survival value for newborn infants, an equally important effect is that it establishes new opportunities for social interaction and social learning. By directing attention toward the social world, the newborn embarks upon what will be its period of greatest postnatal change in brain and behavior, as success in early social adaptive tasks canalizes typical development toward increasingly refined forms of social and communicative competence. As infants gain increasing experience with their surroundings, their initially broad attentional preferences become increasingly attuned to specific signals that are most developmentally relevant. For instance, while newborns show a preference for both human speech *and* rhesus macaque vocalizations, 3-month olds prefer human speech over rhesus calls (Shultz & Vouloumanos, 2010; Vouloumanos, Hauser, Werker, & Martin, 2010). Similarly, infants' discrimination skills become attuned to conspecific and own-race faces within the first 9 months (Kelly et al., 2007; Pascalis, de Haan & Nelson, 2002) and become similarly attuned to native language phonemic contrasts in the first 10 months (Werker & Tees, 1984). In addition to the refinement of preferential attention, infants display increasingly sophisticated social abilities as preferential orientation toward caregivers transitions into face-to-face communication: by 2 months, typical infants show improved ability to maintain eye contact (Blass & Camp, 2001), improved ability to maintain attention (Aslin, 1987), active exploration of internal facial features (Haith, Bergman, & Moore, 1977), and the ability to engage in coordinated affective and vocal exchanges with a communicative partner (Lavelli & Fogel, 2005).

While these feats of early infancy represent remarkable abilities in such otherwise fragile beings, neither the achievements themselves nor the patterns of developmental change are entirely unique to human infant development. In particular, the concept of canalization and the importance of experience in guiding development are well established in many other species. In bird species, for instance, early species-typical experiences, such as exposure to own-species vocalizations, are critical in guiding preferential attention toward socially relevant signals, such as the mother's call (Gottlieb, 1981). When mallard ducklings are devocalized and thereby deprived of embryonic auditory self-stimulation, a preference for the mallard maternal call compared to the call of other species fails to emerge (Gottlieb, 1971, 1975). This demonstrates how the hatchling's early experiences can canalize development, constraining the range of stimuli that elicits preferential attention and guiding the hatchling toward forms of stimulation that are most relevant for survival. In the absence of these early experiences, the auditory preferences of hatchlings remain broadly tuned, responsive to the maternal signals of many species (Gottlieb, 1991). Such a disruption could conceivably have widespread and cascading effects on subsequent development, as reduced preferential attention to conspecifics may diminish opportunities for species-typical learning and contact with conspecifics.

6.2 Adaptive Action and Developing Brain Systems Constrain and Shape One Another

In human infants, examination of neural systems that guide infants' attention to caregivers reveals the ways in which developing brain systems and behavioral capacities both constrain and shape one another. Behavior exerts powerful influences on the development of neural systems by selecting inputs that dynamically modulate neural activity, thereby shaping brain structure and function (Byrge, Sporns, & Smith, 2014). Brain activity, in turn, modulates behavior, creating a circular process whereby "the brain's outputs influence its inputs and these inputs in turn shape subsequent outputs—binding brain networks to the organism's environment over short timescales and cumulatively over developmental time" (Byrge et al., 2014, p. 3).

This intrinsic dependency between brain and behavior is also found in the neural systems that subserve attention to the eyes of others. At birth, the relative maturity of subcortical visual structures, as compared to the relative immaturity of cortical visual structures, may actually function to facilitate the patterns of preferential visual attention described in the previous section. Newborns' direct their rather limited visual attention, using the available subcortical neural resources, toward those stimuli that have the greatest survival value—the faces and eyes of others (Turkewitz & Kenny, 1982). The subcortical visual system (unlike the later-maturing cortical structures) is differentially responsive to visual properties of faces and eyes, such as low-spatial frequency components of the configuration of a face (Morton & Johnson, 1991), top-heavy vertically asymmetrical patterns (Simion, Cassia, Turati, & Valenza, 2001), and high contrast polarity (Farroni et al., 2005); this developmental affordance between available neural resources and physical regularities in the conspecific caregiving environment helps to ensure that newborns are more likely to fixate on faces, and especially the eyes, more than other competing stimuli in the natural environment (Johnson & de Haan, 2001; Johnson, 2005; Morton & Johnson, 1991).

Indirect evidence further supports this notion that neonates' visual biases for face-like stimuli are primarily mediated by subcortical rather than cortical visual circuitry. By about 2 months prenatally, myelination of the subcortical visual pathway begins (Yakovlev & Lecours, 1967), and at birth, the subcortical visual pathway is fully functional. In contrast, the primary visual cortex is relatively immature at birth (Atkinson, 2000; Johnson, 1990; Martin et al., 1999; Morita et al., 2000) and has little influence over visually guided behavior (Csibra, Tucker, Volein, & Johnson, 2000). Myelination of cortical visual pathways begins at the time of birth and does not finish until approximately 4 months, a full month later than subcortical pathways (Yakovlev & Lecours, 1967). Similarly, while subcortical structures such as the lateral geniculate nucleus have completed the majority of their developmental change before birth (Garey & De Courten, 1983; Hitchcock & Hickey, 1980; Khan, Wadhwa, & Bijlani, 1994), primary visual cortical areas undergo a large increase in synaptogenesis in the first months of life (Huttenlocher, de Courten, Garey, & Van der Loos, 1982).

This evidence underscores the developmental affordance between the subcortical visual orienting system of newborns and a social adaptive action that is critical to their survival: attending to the faces and eyes of others. Together, these mechanisms facilitate survival, but they also conspire to encourage social interactions and social learning from the first months of life. As subcortical structures guide newborns' visual attention toward socially relevant stimuli, the act of seeking and attending to such information in turn shapes the developing brain. The amygdala, a subcortical structure that plays a role in both directing and maintaining biases for attending to faces (Adolphs, Tranel, & Damasio, 1998; Bachevalier, 1994; Baron-Cohen et al., 2000; Brothers, 2002) and in reacting quickly to highly salient social stimuli (LeDoux, 1996; Schultz, 2000), has reciprocal connections with ventral visual areas (Amaral & Price, 1984) and projects information about salient stimuli to cortical areas involved in face processing in adults, such as the lateral occipital cortex, fusiform, and orbitofrontal cortex (Pasley, Mayes, & Schultz, 2004). During the first 2 months of life, connections between the amygdala and regions, such as the fusiform, lateral occipital cortex, and orbitofrontal cortex, may serve to increase the activity of cortical areas that would otherwise receive only weak input from functionally immature cortical visual areas (Johnson, 2005), leading to the subsequent specialization of these regions for processing faces and other social stimuli. As early experiences accrue, so too does the synaptogenesis to and from, and the myelination of, these cortical visual pathways.

Existing studies of brain function in infancy provide evidence of this type of neural specialization, specifically for stimuli that hold the greatest adaptive value to typically developing infants, even by the second month of life. Two-month olds show activation in cortical areas within the adult face-processing network, including the right fusiform gyrus and bilateral inferior occipital cortex, when viewing human faces (Tzourio-Mazoyer et al., 2002). Three-month olds show selective activation in left superior temporal and angular gyri in response to forward compared with reversed speech (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002) and a larger event-related potential (ERP) N290 component amplitude and shorter latency in response to human compared with monkey faces (Halit, De Haan, & Johnson, 2003). Finally, 3- to 7-month olds show activation of the right middle temporal gyrus in response to human vocalizations compared with nonspeech vocalizations and environmental sounds (Blasi et al., 2011).

Although studies examining the relationship between developmental change in brain function and behavior are scant, there is some evidence that cortical networks undergo a process of specialization that coincides with the refinement of social adaptive action in early infancy. A functional magnetic resonance imaging (fMRI) study of 1- to 4-month-old infants revealed increased neural selectivity for speech over biological nonspeech sounds during a developmental period that coincides with the attunement of infants' listening preferences for human speech over rhesus monkey calls (Shultz, Vouloumanos, Bennett, & Pelphrey, 2014). Specifically, a negative correlation was observed between gestational age and response to biological nonspeech sounds within a speech-sensitive region of left temporal cortex. An increased selectivity for speech during this period in development represents a process that may be both a cause and consequence of the tuning of infants' listening preference for speech: as infants' active seeking of speech likely modulates neural activity, these neural changes, in turn, modulate behavior.

6.3 Early Departures from Normative Trajectories in ASD

While, as reviewed earlier, typically developing infants show a remarkable attunement to the social world, with evidence of maturational brain change that constrains and guides attunement, the available evidence suggests that this is not the case for individuals with autism. A striking feature of the disorder is that individuals with ASD, even intellectually capable adults, exhibit deficits in the very social adaptive actions that have immediate survival value and provide the platform for future social development (Kanner, 1943). For example, while typical newborns as young as 2-days old orient preferentially to socially relevant signals such as biological motion and the eyes of others (Farroni et al., 2002; Simion, Regolin, & Bulf, 2008), 2-year-old children with ASD fail to do so (Jones et al., 2008; Klin et al., 2009). By demonstrating that skills present from birth in typical newborns are disrupted in ASD, these findings point to early departures from normative processes of development. Following from a model of child development where success in social adaptive tasks guides typical development toward increasingly refined skills in an iterative process, early departures from such processes will likely lead to atypical outcomes as development becomes increasingly atypical (Jones & Klin, 2009).

The potentially devastating and accumulative consequences of early disruptions in basic mechanisms of social adaptive action highlight the period of early infancy as a target for research aimed at understanding the emergence of the syndrome. While reduced attention to social stimuli has been widely reported in children and adults with ASD, less is known about the course of such deviations from normative developmental trajectories in early infancy and their impact on subsequent outcomes. Because ASD is rarely diagnosed before 18 months (Klin et al., 2004), the method of choice for research of infancy in autism necessarily involves prospective study and longitudinal following of the "baby siblings" of children already diagnosed with an ASD. Within siblings followed prospectively, the recurrence rate of ASD is high, estimated at 18.7% (Ozonoff et al., 2011).

To date, the main focus of longitudinal studies of baby siblings has been on the timing and diagnostic manifestation of autistic symptomatology. Within the first 18 months of life, infants with ASD already show signs characteristic of the disorder:

- At 6 months: reduced attention to social scenes and faces (Chawarska, Macari, & Shic, 2013).
- At 12 months: unusual patterns of object exploration and stereotyped, repetitive behaviors (Loh et al., 2007; Ozonoff et al., 2008), reduced social interest and atypicalities in eye contact, affect, orienting to one's name, imitation, and social smiling (Hutman et al., 2010; Ozonoff et al., 2010; Wan et al., 2013; Zwaigenbaum et al., 2005), deficits in vocal production, language comprehension, and gesture production (Mitchell et al., 2006; Paul, Fuerst, Ramsay, Chawarska, & Klin, 2011), and lower rates of requesting behaviors (Rozga et al., 2011).
- At 14 months: cognitive deficits, as measured by the Mullen Scales of Early Learning (Landa & Garrett-Mayer, 2006).
- At 15 months: deficits in joint attention and triadic communication (Sullivan et al., 2007; Yoder, Stone, Walden, & Malesa, 2009).
- At 18 months: atypicalities in play behavior (Christensen et al., 2010).

While these studies provide important insights into the manifestation of ASD at developmental time points prior to the typical age at diagnosis, most of the symptomatology described is likely to have arisen as a consequence of atypical early social experiences. Few studies have examined disruptions to basic mechanisms of social adaptive action that are the putative building blocks of later social abilities, and no prospective longitudinal studies have examined departures from such processes in the first 6 months of life. By failing to measure the developmental antecedents of ASD symptomology, we run the risk of measuring the culmination, rather than the unfolding, of departures from typical social behavior and experience.

This state of affairs was the impetus for our most recent study of attention to the eyes of others in infants later diagnosed with ASD (Jones & Klin, 2013). Our motivation for measuring preferential attention to eyes was twofold. First, preferential attention to eyes is a phylogenetically well-conserved mechanism of social adaptive action (Emery, 2000) that plays a key role, as summarized earlier, in canalizing typical social development: eye-looking serves to entrain babies to the social signals of their caregivers and also establishes opportunities for learning through social interaction. Second, preferential attention to the eyes of others is developmentally early emerging, present from the first days of life in typical infants but significantly reduced in 2-year olds with ASD (Farroni et al., 2002; Jones et al., 2008).

We collected data from infants at low-risk and at high-risk for ASD at 10 time points: at months 2, 3, 4, 5, 6, 9, 12, 15, 18, and 24. Diagnostic status was ascertained at 36 months. Infants viewed prerecorded video scenes of caregivers looking directly at the children, with the caregivers making entreating overtures and enacting typical infant routines (preparing for a meal, engaging in motherese vocal communication, singing a nursery rhyme, etc.). Infants' visual scanning was measured with eye-tracking equipment while watching the videos. The percent of visual fixation time to eyes, mouth, body, and object regions was measured. Visual fixation time to eyes for the typical children created normative growth curves of social visual engagement against which to compare the data for infants later diagnosed with autism. Typically-developing (TD) children, from 2 to 24 months, looked more at the eyes than at any other region of the screen (mouth, body, objects); eye fixation increased steadily from 2 to 9 months and then remained relatively stable until the age of 24 months (Fig. 6.2a).

In infants later diagnosed with ASD, growth curves of social visual engagement follow a very different developmental course. Eye fixation began at a level similar to TD children, but then declined steadily from the 2-month starting point, arriving at a level that was approximately half that of TD children by the 24-month endpoint (Fig. 6.2e). This pattern holds two key implications for our understanding of the developmental pathogenesis of social disability in ASD. First, these results pinpoint the *developmental onset* of the widely reported reduction in preferential attention to eyes in ASD; rather than a congenital absence of attention to eyes in ASD, early levels of eye-looking at 2 months of age seem to begin at normative levels, with the decline in eye-looking beginning during the period from 2 to 6 months. Second, these results reveal the impact of deviations from normative trajectories of social visual engagement on subsequent outcomes. The decline in eye fixation from 2 to 6 months was significantly associated with diagnostic outcome at 36 months, providing a strong marker of later diagnosis 1½ years before children can be diagnosed conventionally and 2½ years before they can be diagnosed stably. In addition, the extent of decline in eye-looking among children with ASD was a strong predictor of their level of social disability at outcome (as measured with standardized clinical instruments): those whose levels of eye-looking declined most rapidly were also most socially disabled in later life.

To our surprise, however, these data contradicted prior hypotheses postulating a congenital absence of social adaptive orientation in ASD: early levels of eye-looking were not immediately diminished in infants with ASD; instead, infants with ASD exhibited a slight but significant increase in eye-looking at 2 months, which then declined (Fig. 6.2c and d). Several points are worth noting regarding this preliminary finding of "normative" eye-looking at 2 months of age in ASD. Although these data appear to show that orienting to eyes is present in early infancy in ASD, this does not necessarily mean that the behavior itself is "normative" or representative of eye-looking in typical social development. Put differently, although the superficial levels of eye-looking (i.e., high magnitude of eye-looking at 2 months of age) are present, the developmental processes underlying such eye-looking may be markedly different in infants with ASD. Indeed, the rate-of-change data indicate that the underlying rate of change in eye-looking already differs between typical

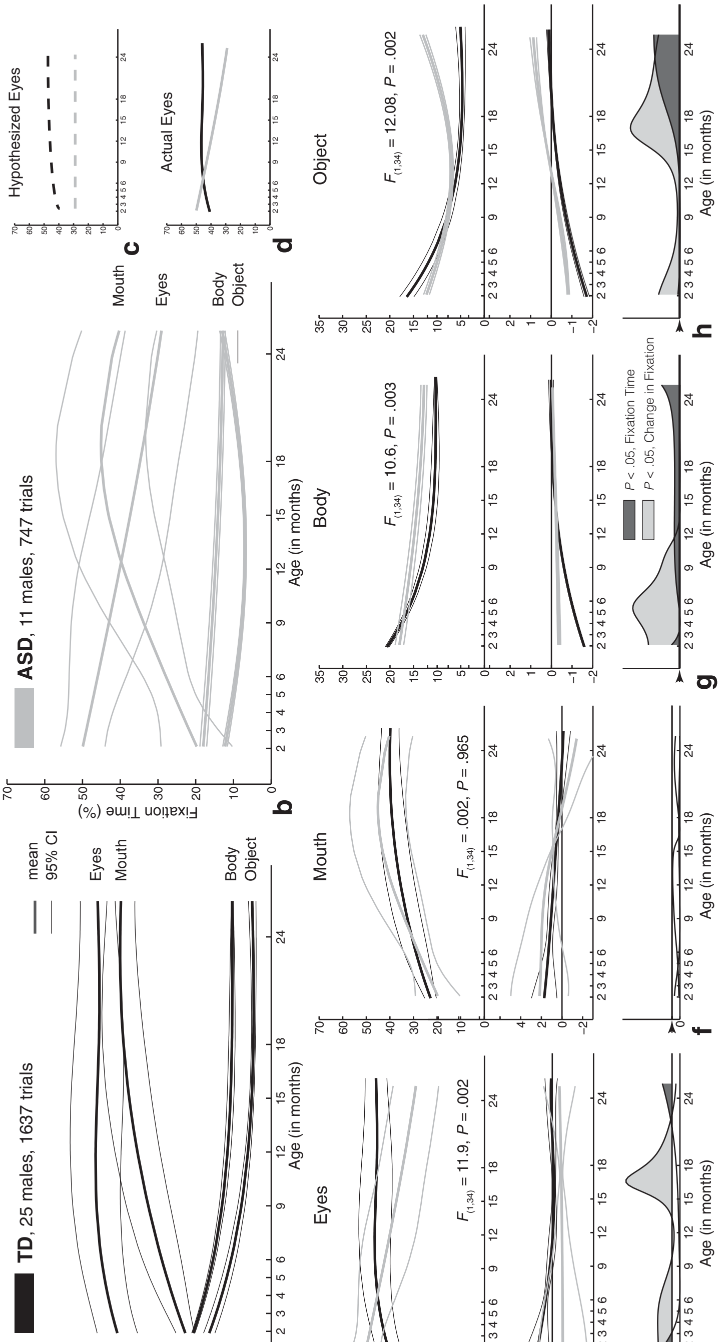

Fig. 6.2 *Growth charts of social visual engagement for typically developing children and children diagnosed with ASD, originally published in Nature (2013).* **a, b** Fixation time to eyes, mouth,

infants and infants with ASD at 2 months of age. In addition, magnitude of eye-looking is slightly, but significantly, higher at 2 months of age in infants with ASD. While this finding should be replicated in a larger sample, the relatively high level of eye-looking at 2 months in ASD may already represent a departure from normative developmental processes. Thus, while eye fixation may look superficially similar in the early months, the underlying developmental processes may already be markedly different.

Despite the possibility that initial eye-looking in ASD may not reflect normative developmental processes, the mere presence of early eye-looking, as opposed to an outright absence, constrains hypotheses about what processes may be disrupted in ASD. Intriguingly, the finding of superficially normative levels of eye-looking, followed by a decline thereafter, maps onto preexisting literatures relating to early typical transitions in face expertise and early infant transitions in adaptive behavior.

In typical development, preferential orientation to faces (present at birth) declines between 4 and 6 weeks before reemerging at approximately 2 months (Johnson et al., 1991), a pattern that mirrors that of other neonatal reflexive actions, such as orienting to auditory sounds and imitating others (Dodwell, 1983; Field, Muir, Pilon, Sinclair, & Dodwell, 1980; Field, Goldstein, Vega-Lahr, & Porter, 1986; Maratos, 1982). A model for this transition has been proposed, moving from "experience-expectant" mechanisms (more "reflex-like," and presumably more proximal to gene determination) to "experience-dependent" mechanisms (building on the iterative experiences and resultant learning that arise as a consequence of the initial, reflex-like behaviors; Bjorklund, 1987; Emde & Harmon, 1972; Johnson, 1990; Johnson et al., 1991).

The neural mechanism that underlies these changes is thought to be a shift from subcortical to cortical control, with initial predispositions (subserved by subcortical structures) declining as cortical control develops. This suggestion is strengthened by evidence of the early development of the visual system: as reviewed above, while the subcortical visual pathway is functional at birth, the primary visual cortex remains relatively immature and has little influence over visually guided behavior (Atkinson, 2000; Johnson, 1990; Martin et al., 1999; Morita et al., 2000). Retinocortical pathways become fully functional approximately 2 months after birth (Atkinson, 2000; Braddick, Wattam-Bell, & Atkinson, 1986)—when our data collection begins—and also at approximately the same age at which ERP and positron emission tomography (PET) studies show evidence of cortical specialization for attention to faces (Halit et al., 2003; Tzourio-Mazoyer et al., 2002).

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body, and object from 2 until 24 months in (**a**) typical development *(TD)* and (**b**) autism spectrum disorder *(ASD)*. **c, d** Contrary to a congenital reduction in preferential attention to eyes in ASD, (**d**) children diagnosed with ASD exhibit mean decline in eye fixation. **e–h** Longitudinal change in fixation to (**e**) eyes; (**f**) mouth; (**g**) body; and (**h**) object regions. Dark lines indicate mean growth curves; light lines indicate 95 % confidence intervals *(CI)*. Top panels in **e-h** plot percent fixation; middle panels plot change in fixation (the first derivative, in units of % change per month); and bottom panels plot *F* value functions for between-group pointwise comparisons as a function of age in months. Significant differences are shaded in medium gray for comparison of fixation data and light gray for comparison of change-in-fixation data

This maturational timeline is well fitted by the changes in behavior that we observe in typically developing infants. At 2–3 months of age, typical infants appear to be in transition between reflex-like orientation and emerging, cortically controlled preferential attention: the 2-month time point would thus be situated between one downward developmental trend (the waning of subcortically controlled, reflex-like eye fixation) and one upward trend (the increasing, experience-dependent, cortically-mediated eye fixation). This maps onto both the relative low point in eye fixation by typical infants at 2 months of age and the increase in eye fixation from 2 until 9 months. In contrast, the data for infants later diagnosed with ASD suggest a reflex-like orientation that appears to persist beyond its developmentally appropriate time window (leading even to a slight increase in ASD relative to typical eye fixation at 2 months, Fig. 6.2e). In the absence of the emergence of cortically controlled, experience-dependent eye fixation, the reflex-like (subcortically mediated) orientation appears to persist before declining.

6.4 Departures from Normative Trajectories Yield Increasingly Atypical Behavior and Atypical Neural Specialization

Our recent eye-tracking results indicate that subcortically mediated reflex-like attention to eyes may fail to transition to cortically mediated experience-dependent eye fixation at around the second month of life in ASD. However, rather than suggesting an outright failure of cortical control of preferential visual attention in ASD, the available data suggest a co-opting of those mechanisms by attention to *other* features in the environment. For instance, instead of maintaining and reinforcing attention to eyes, infants with ASD showed high levels of mouth and object fixation, with fixation on others' mouths increasing from month 2 until approximately month 18 and object fixation rising by 24 months to twice the level of typical controls (see Fig. 6.2f and h). Data from older infants and toddlers further support the notion that individuals with ASD use ostensibly intact attentional systems to actively seek out alternate experiences. For example, at 12 months of age, infants with ASD show reduced social interest, accompanied by a tendency to fixate on particular objects in the environment (Hutman, Chela, Gillespie-Lynch, & Sigman, 2012; Zwaigenbaum et al., 2005). In addition, unlike typical toddlers, toddlers with ASD show a preference for nonspeech compared with speech (Klin, 1991; Kuhl, Coffey-Corina, Padden, & Dawson, 2005) and for dynamic geometric images compared to dynamic social images (Pierce, Conant, Hazin, Stoner, & Desmond, 2011). Finally, studies from our laboratory demonstrate that toddlers with ASD are highly sensitive to the presence of nonsocial, physical contingencies (audiovisual synchronies between point lights) (Klin et al., 2009) and are more engaged by physical, rather than social events (Shultz et al., 2011).

Together these results suggest that a child with autism, from as early as 2 months of age, is learning from a world dominated by physical rather than social events. Given the canalizing role of preferential attention to social stimuli in typical development, how might attention toward physical, rather than social, stimuli impact developmental outcomes? Our longitudinal eye-tracking data provide an initial answer to this question by demonstrating that reduced attention to others' eyes between 2 and 6 months of age is a strong predictor of a later diagnosis of ASD at 36 months. In addition, more pronounced atypical experiences may actually *worsen* developmental outcome, as steeper decline in eye fixation was associated with more severe social disability (Jones & Klin, 2013). Although not examined in our eye-tracking study, we further predict that disruptions to early mechanisms of social adaptive action may have widespread cascading effects on many areas of development, as children with ASD actively seek alternate experiences as they try to make sense of their surrounding world (Jones & Klin, 2009).

This hypothesis is nicely illustrated by the case of diverging developmental processes underlying attention to the mouth in typical toddlers and toddlers with ASD. While attention to the mouth is a social adaptive action in typical development, proposed to play a key role in the development of spoken communication in typical infancy (Lewkowicz & Hansen-Tift, 2012), research from our laboratory has revealed that attention to the mouth in toddlers with ASD may instead be driven by sensitivity to audiovisual synchrony (Klin et al., 2009). Put differently, the available evidence suggests that typical children and children with ASD seek and attend to the mouths of others for very different reasons, with typical children viewing mouths as a source of spoken social communication and toddler with ASD viewing the mouth as a source of audiovisual synchrony. These very different goals likely yield different learning experiences and expertise, and, at a later developmental time point, may result in different communication and language outcomes: typical children develop adaptive social communication skills (Locke, 1995), whereas children with ASD who do acquire language often do so in a way that is decoupled from social meaning, resulting in speech that is rote rather than contextualized (Tager-Flusberg, Paul, & Lord, 2005); facts that are memorized rather than episodic and personalized (Klin et al., 2007; O'Shea, Fein, Cillessen, Klin, & Schultz, 2005); and in extreme cases even results in instances of hyperlexia in ASD, when words are read without any concept of their meaning (Grigorenko, Klin, & Volkmar, 2003).

Given that infants contribute very actively to their own brain specialization by attending differentially to the surrounding environment (Byrge et al., 2014; Joseph E LeDoux, 2003), the accumulation of atypical social experiences in ASD is likely to have a profound impact on shaping brain structure and function. The brain, in turn, modulates behavior, creating an iterative process whereby atypical experiences and altered brain specialization become compounded over developmental time (Byrge et al., 2014). Although few studies have examined brain–behavior relationships prospectively and longitudinally in the first months of life, existing evidence supports the notion of early emerging alterations in brain structure and function in ASDs that are consistent with reduced social attention. Unlike typical controls, 6- to 10-month-olds later diagnosed with ASD fail to modulate the amplitude of a face-sensitive ERP component, the P400, in response to viewing eye-gaze shifts toward versus away from them (Elsabbagh et al., 2012). Similarly, 10-month-olds later diagnosed with ASD show a prolonged P400 latency along with late and less persistent gamma activity in response to direct eye gaze (Elsabbagh et al., 2009). Finally, in contrast to control infants, 9-month-olds at high risk for ASD do not show modulation of P400 latency when viewing their mother's face compared with a stranger's face (Key and Stone, 2012) and 10-month-olds at high risk for ASD show a faster N290 ERP component in response to objects compared with faces (McCleery, Akshoomoff, Dobkins, & Carver, 2009).

Consistent with altered brain specialization for social processing, older children and adults with ASD show reduced functional connectivity and hypoactivation in a network of brain regions implicated in social processing in typical adults (Gotts et al., 2012). For instance, hypoactivation has been reported in the superior temporal sulcus in response to biological motion (Freitag et al., 2008; Herrington et al., 2007; Kaiser et al., 2010); in the medial prefrontal cortex, superior temporal sulcus, and temporal poles during tasks that involve thinking about the mental states of others (Castelli, Frith, Happé, & Frith, 2002); in the mirror neuron system (including the inferior frontal gyrus and inferior parietal lobule) during imitation (Dapretto et al., 2006); and in the amygdala and fusiform gyrus in response to faces (Schultz, 2000). Although the relationship between reduced social attention and disruptions to social brain regions has not been systematically explored, some evidence suggests that brain structures typically subserving social processing become "co-opted" for processing alternate stimuli of greater interest to individuals with ASD. In one intriguing case (Grelotti et al., 2005), an adolescent with ASD honed his interests in Digimon cartoons over many years; he displayed activation of his amygdala and fusiform gyrus for perceptual discriminations involving Digimon, but not for those involving familiar or unfamiliar faces. This case suggests that abnormal functioning of the fusiform in ASD may arise as a consequence of years of reduced social interest and atypical experiences.

6.5 Conclusions

Adaptive action in response to environmental demands constrains development in an iterative process that builds on older structures to generate new ones. In this view, a child's developmental outcome is shaped not only by genetic and neural predispositions, but also by the experiences that arise as a consequence of those predispositions (Jones & Klin, 2009). For typical infants, predispositions to attend to the social world from the first moments of life canalize development, resulting in successively more complex social cognitive abilities and neural specialization. For infants with autism, failure to attend to social stimuli, and looking at other parts of the world instead, suggests an altered path for learning, with cascading effects on further brain and behavioral development.

This framework highlights the pressing need to study deviations from the building blocks of typical development in order to understand developmental outcomes, echoing Karmiloff-Smith's proposal that, "development itself is the key to understanding developmental disorders" (Karmiloff-Smith, 1998). By measuring departures from normative trajectories of brain and behavioral development, we can begin to identify disruptions in socialization (such as lack of attention to eyes) and map their timing and consequences for subsequent social cognitive growth, brain development, and syndrome expression.

This approach holds promise for informing understanding of brain-behavior pathogenesis in ASD. Given the late age of actual diagnosis of ASD (Centers for Disease Control and Prevention, 2014), the majority of current research findings are based on work with relatively older children. This leaves the possibility that much of our existing knowledge of autism reveals more about the consequences of having had autism (often for many years) than it does about the causes and underlying mechanisms from which a disability arose (Jones & Klin, 2009). Quantifying the earliest developmental antecedents of the condition—such as a decline in looking at the eyes of others—offers the opportunity to study the unfolding, rather than the culmination, of many years of often increasingly aberrant behavior and atypical experience (Grelotti, Gauthier, & Schultz, 2002). However, it is important to note that reduced orienting toward caregivers does not cause autism in and of itself. Clearly more work is needed to understand how these altered predispositions initially arise in infants with ASD. Nonetheless, early departures from normative processes of development represent both a sign of social disability and a compounding influence on subsequent social disability. Mapping these early departures in ASD holds promise for identifying important areas of future research and may constrain future hypotheses about the causal mechanisms underlying ASD. Indeed, our longitudinal eye-tracking findings refute hypotheses of a congenital absence of preferential social attention in ASD and instead highlight a narrow period of early infancy, spanning the transition from experience-expectant to experience-dependent mechanisms, as a critical focus for future investigation.

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Chapter 7
Aberrant Social Attention and Its Underlying Neural Correlates in Adults with Autism Spectrum Disorder

Jennifer C. Bush and Daniel P. Kennedy

Humans are highly social beings and display a strong early preference for seeking out and processing social information from their environment. For instance, newborn infants as young as 10 minutes old will show preference to face-like patterns over "scrambled" face patterns (Goren, Sarty, & Wu, 1975; Johnson, Dziuarawiec, Ellis, & Morton, 1991), 4-day-old infants have been shown to recognize their mothers (Field, Cohen, Garcia, & Greenberg, 1984), and 2–5-day-old newborns can discriminate between direct and averted eye gaze (Farroni, Csibra, Simion, & Johnson, 2002).

Social preferences and attention emerge early and spontaneously, and likely set the stage for the development and refinement of various social skills that are critical for successful social behaviors exhibited over one's lifetime (Chevallier, Kohls, Troiani, Brodkin, & Schultz, 2012). This includes the ability to infer the feelings of others, effectively communicating one's thoughts and feelings, and maintaining social relationships, among other important social functions. And, while beyond the scope of the present chapter, it is worth highlighting that social attention is a particularly far-reaching process, as it influences functional domains beyond those classically thought of as social. For instance, the development of language has been shown to rely critically on a highly social process—that of initiating and responding to the attention of others (i.e., joint attention) (Kuhl, 2007; see Bruinsma, Koegel, & Koegel, 2004 for review).

While social attention and early social preferences develop spontaneously for most people, this is not always the case. In particular, individuals with autism spectrum disorder (ASD) exhibit striking abnormalities in social attention. These abnormalities seem to emerge sometime within the first year of life and persist

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over the life span, although they may manifest in more subtle ways in later childhood, adolescence, and adulthood, and therefore require more sensitive tools to quantify them. Shultz, Jones, and Klin (Chap. 6, this volume) covered the early development of social attentional abnormalities in autism. Here, we will review some of the social attentional abnormalities in older individuals with an ASD, and discuss the implications of these abnormalities on social functioning.

7.1 ASDs and Early Emergence of Abnormal Social Attention

Individuals diagnosed with ASD often have profound difficulties navigating the social world, exhibiting striking deficits in many areas that require complex social cognitive abilities. The term “spectrum” is crucial in understanding ASD, as there is a wide range of symptoms and degree of affectedness, resulting in incredible individual variation. This heterogeneity was first highlighted in Leo Kanner’s (1943) original case studies of ASD, with individuals exhibiting a wide variation in language and social abilities. This heterogeneity no doubt contributes to the challenges associated with early identification and diagnosis, as well as the efforts to elucidate the mechanisms underlying ASD behavior and cognition. Though individuals with ASD exhibit impairment in several functional domains, Kanner highlighted the social and emotional disturbances as the core features of the disorder, arguing that “the outstanding, ‘pathognomonic’, fundamental disorder is that the children’s inability to relate themselves in the ordinary way to people and situations of the beginning of life” (Kanner, 1943).

Numerous studies have documented the early emergence of social attentional abnormalities in young children with ASD. As a review and discussion of this topic can be found in the previous chapter (Shultz et al., Chap. 6, this volume), we do not intend to cover this topic in any depth. For context, however, we provide a brief description of several key findings.

Retrospective studies examining home videos report that by 12 months of age, children later diagnosed with ASD are less likely to look at faces of other people (Osterling & Dawson, 1994; Adrien et al., 1993), fail to orient to their names (Maestro et al., 2001; Osterling, Dawson, & Munson, 2002), show poor eye contact (Adrien et al., 1993; Clifford, Young, & Williamson, 2007), and show reduced initiation of, and response to, joint attention (Osterling & Dawson, 1994; Nadig et al., 2007; Sullivan et al., 2007)—a process that by definition involves social attention, and directing the attention of another social agent. Prospective longitudinal studies of infants at risk for an ASD, but whose young age precludes reliable diagnosis, also report similar differences. Infants later diagnosed with ASD show differences in visual attention, have reduced eye contact, look more at mothers’ mouths than eyes, exhibit lower levels of social smiling, reduced bids for joint attention, and use significantly fewer gestures than typically developing infants

(Mitchell et al., 2006; Zwaigenbaum et al., 2005; Nadig et al., 2007; Ozonoff et al., 2010). These altered patterns of attention are generally thought to relate to the later emergence of autism, but how?

While the causes of abnormal social attention in ASD remain uncertain, early abnormalities in social attention are thought to have cascading downstream effects that affect typical neural, cognitive, and behavioral development (Mundy & Neal, 2000; Chevallier et al., 2012). In other words, abnormal social attention may result in diminished social expertise, which then impacts the behavioral, cognitive, and neural specialization for social processes generally, resulting in further atypical allocation of social attention, and so on. This continues on in a self-reinforcing cycle across development that ultimately results in atypical social functioning. Thus, understanding the earliest points within this developmental derailment may be crucial to understanding how autism emerges, and essential in informing early intervention.

However, social attention needs to also be studied beyond infancy and across developmental ages, as social attention as a process can profoundly shape social functioning at all ages across the life span. ASD is a life-long disorder, and it is well accepted that social attentional abnormalities do not simply disappear after infancy and childhood. As described in this chapter, social attentional abnormalities are present into adulthood in ASD.

Thus, it is essential to understand specifically how altered attention in adolescents and adults with ASD may continue to impact their behavior, cognition, and brain functioning. Some social abnormalities may be a consequence of early attentional abnormalities interacting over the course of development (e.g., lack of expertise for faces), but some of these differences may simply reflect persistent and atypical attentional processes at a particular moment in time (e.g., missing an important social cue about someone’s emotional state).

There is evidence that at least some of what is claimed to be abnormal in terms of behavior, cognition, and brain activity in individuals with ASD may be accounted for by the latter. More specifically, altered patterns of attention in the moment may transiently influence behavior, cognition, and brain activity, but not reflect a more persistent dysfunction. Indeed, this is a major component of many interventions targeting social skills in adolescents and adults with autism—what are the important socially relevant cues/information in the immediate environment, and how should these cues be attended to and interpreted?

In this chapter, we focus on aberrant social attention as it is manifested in adolescents and adults diagnosed with ASD. We first review the literature detailing behavioral differences in social attention in individuals with ASD, and go on to discuss possible functional consequences (i.e., social deficits) that may be attributed to disrupted social attention. We also discuss some of the research on the neural correlates underlying atypical social attention in ASD, with a particular focus on several regions involved in social attentional processes. We conclude by highlighting some outstanding questions and discussing future promising directions for research on social attention in ASD.

7.2 Eye Tracking as an Indispensable Tool for Social Attention Research

Evidence for altered social attention was presented alongside the first clinical description of ASD. Kanner described children with ASD as appearing to be oblivious or indifferent to people, failing to look at both physicians and family members alike (Kanner, 1943). However, some of the first quantifiable experimental evidence of social attentional abnormalities came decades later. Langdell (1978) showed familiar faces to ASD and control individuals that were only party visible (i.e., just the eyes, nose, mouth, or hair). Participants were then asked to identify the familiar person from this impoverished image. Because the ability of individuals with ASD to recognize familiar individuals by their mouths alone was superior to controls, Langdell concluded that children with ASD must be looking at and attending to faces differently in their everyday lives (Langdell, 1978).

While measures of accuracy and reaction time can be used effectively to infer social attentional processes, as shown by Langdell, a perhaps more straightforward way to determine an individual's focus of attention is to measure where they choose to look. Eye tracking is a methodology/technology that can do just that, and has proven to be an extremely useful tool for investigating patterns of typical and atypical social attention. Most modern eye tracking relies on infrared light and high-speed sensors that can noninvasively track the movement of eyes at high sampling rates (ranging from 30 Hz to 2000 Hz).

Since we tend to look at what we are interested in and wish to attend to[1], eye tracking provides us with a near real-time insight into cognitive processes via a rapid, accurate, and largely automatic motor response. This is in contrast to other behavioral measures that often require explicit instructions, training, deliberate conscious motor control, or self-insight (e.g., responding via button presses or self-report measures). Furthermore, because eye tracking merely requires a participant to sit relatively still and look at a screen, it can and has been used across ages and levels of cognitive functioning, allowing scientists to test and draw comparisons across a wide range of participants. Given that social attentional abnormalities are thought to be a significant core feature of ASD, eye tracking has become an indispensible tool in this field of research. While the majority of the studies we describe in this chapter use eye tracking as a primary methodology, other non-eye tracking-based experiments will also be discussed because other approaches, like that used by Langdell, can also reveal novel and important insight into social attention in ASD.

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[1] While we can dissociate our eye movements from the focus of our attention (von Helmholtz, 1909/1962; Posner et al., 1980), generally our attention corresponds to our overt eye movements.

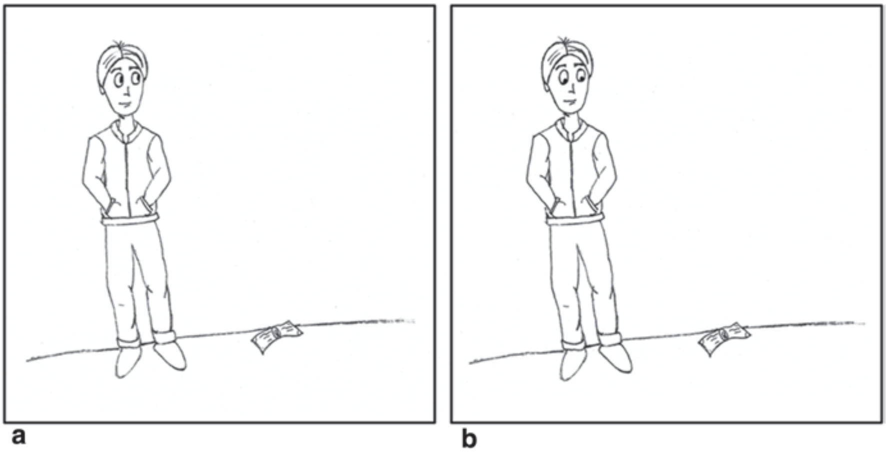

Fig. 7.1 *The eyes within a face can communicate one's attention and mental state.* The only difference between **a** and **b** is the location of the person's eye gaze. From drawing **b**, we might infer that the person is aware of the dollar on the ground, and from this we may predict that he will bend down to pick it up, a prediction we may not make based on drawing **a**. (Image courtesy of Susannah Burkholder)

7.2.1 Attention to Faces and Eyes in ASD

Faces are a key ingredient of social perception and interaction. A large amount of nonverbal social communicative information is conveyed by faces, and disproportionately so by the eyes in particular. Movement of muscles within the face can communicate complex emotional states, indicating a variety of emotional or mental states, including happiness, sadness, surprise, fear, and so on (Duchenne, 1862/1990; Darwin, 1872; Ekman, 1993). Beyond emotional expressions, the eyes within a face can communicate the target of one's attention, and give insight into what a person may be thinking about or planning to do next (see Frischen, Bayliss, & Tipper, 2007 for review). For example, if someone is looking at a dollar bill on the ground, we might infer something about their mental state—e.g., that they are aware that the dollar is on the ground—and predict something about their future behavior—e.g., that they may bend down to pick it up (Fig. 7.1).

Given the richness of social information derived from faces, it should come as no surprise that individuals are drawn to faces, and disproportionately so to the eye region. This is seen at the earliest stages of life (Goren et al., 1975; Maurer & Salapatek, 1976) and persists over development into adulthood. However, this drive to attend to faces and eyes seems to be weaker in individuals with ASD, as noted in the clinical descriptions of ASD (Kanner, 1943; Adrien et al., 1993; Clifford, Young, & Williamson, 2007), and further detailed in experimental tasks described below.

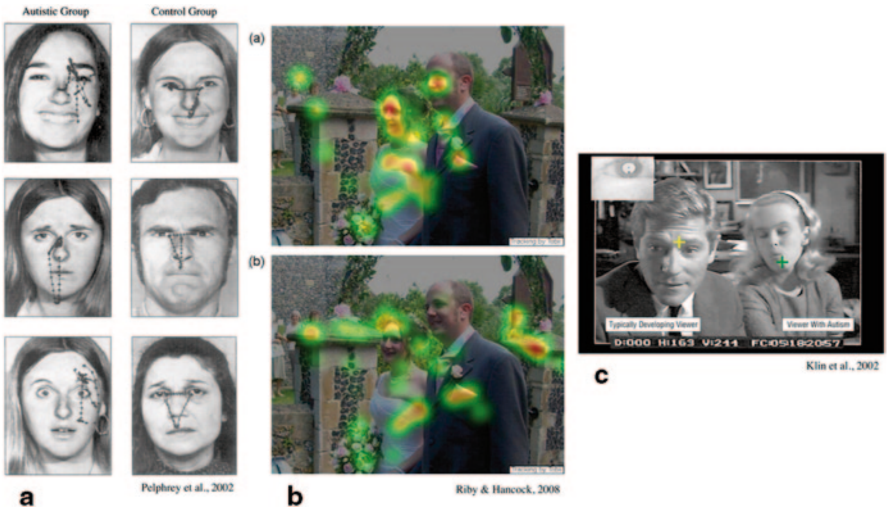

Fig. 7.2 *Differences in eye movements between ASD and NT individuals across several studies*. **a** Individuals with ASD spent a smaller proportion of time examining core features of the face (e.g., eyes, nose, and mouth; Pelphrey et al., 2002). **b** Compared to the controls, the ASD group spent less time looking at faces in complex scenes (warmer colors indicate longer fixation duration; Riby & Hancock, 2008). **c** Individuals with ASD fixated less on eyes and more on the mouth region compared with controls (Klin et al., 2002). The fixation point of an ASD viewer is in *green*, and an NT viewer is in *yellow*. Reprinted with permission

Pelphrey and colleagues (2002) were one of the first to address the question of how adults with ASD look at human faces. They used eye tracking to compare the locations of gaze between ASD and neurotypical (NT) adult controls when viewing pictures of faces portraying basic emotions (i.e., happy, sad, angry, disgusted, and afraid). Regardless of task demands (either freely viewing the image or identifying the emotion portrayed by the face), qualitative differences in scanpaths between groups were evident (Fig. 7.2). Individuals with ASD devoted less time to the core features of the face (i.e., nose, mouth, and eyes), and this effect was particularly pronounced for the time spent fixating the eyes. In addition to differences in gaze, the ASD group performed worse in the emotion identification task, more often confusing anger with fear. The link between emotion recognition and gaze to core features of the face was not assessed in their study, perhaps due to the relatively small sample size. Yet, a relationship between the two seems quite plausible, and this has been tested more directly in subsequent studies (e.g., Corden, Chilvers, & Skuse, 2008), which we discuss later on. It is important to note that all tested participants had IQs in the normal range, suggesting that the findings could not be attributed to a difference in general cognitive ability.

In another early study, differences in gaze were also found when adolescents and young adults with ASD viewed dynamic social stimuli (Klin, Jones, Schultz, Volkmar, & Cohen, 2002). Participants in this study watched clips from the movie *Who's Afraid of Virginia Woolf*, a black and white film characterized by intense emotions and social interactions among the characters. The choice of using a dynamic video as a stimulus was a purposeful one and well motivated. The dynamic nature of videos and the associated visual and social complexity of this particular stimulus better reflect the demand characteristics of social situations encountered in the real world (and represents the type of stimuli that individuals with ASD often find challenging to understand). Klin and colleagues found that the groups showed quantifiable differences in how they looked at the video—adults with ASD spent less time looking at the eyes, and more on the mouth, body, and background/object regions, compared with age and verbal IQ matched controls. Consistent with the findings from Pelphrey et al. (2002), the amount of time spent fixating the eye region was the best predictor of group membership (Klin et al., 2002).

These atypical gaze patterns persist even when individuals with ASD are viewing images of familiar faces (Sterling et al., 2008). In this study, ASD and NT adults matched on age and IQ passively viewed familiar (e.g., family and friends) and unfamiliar faces. It was originally hypothesized that the ASD group would exhibit more normative gaze due to a heightened motivation to look at emotionally salient and familiar people. Overall, the NT group spent a greater proportion of time looking at the eyes regardless of familiarity, and made significantly more fixations to the eyes when looking at unfamiliar faces compared with familiar faces. In contrast, the ASD group did not display patterns of gaze that indicated any distinction between familiar and unfamiliar faces, and exhibited atypical attention regardless of familiarity.

It should be kept in mind that the majority of studies of visual attention in ASD, with several notable exceptions such as the study by Klin and colleagues (2002) described above, have utilized visually cropped and static faces in isolation, without a visible body or any other type of context. Thus it is possible that results derived from such studies are more informative specifically regarding face processing, rather than a broader reflection of the allocation of attention to social information more generally (Sasson, 2006). Faces are often considered to be a special category of stimuli (Kanwisher, McDermott, & Chun, 1997), and a face in the absence of any social context may not reflect how one might view that same face in a more embedded, naturalistic context in which they typically are encountered. This naturalistic context poses additional processing demands, notably including selection of the relevant parts of the scene, which we think perhaps better reflects the clinical descriptions of altered social attention in ASD. For example, Kanner (1943) did not note that the children failed to look at his eyes, but rather that they failed to look at his face. (As an aside, without eye tracking it is actually very difficult to know exactly where on your face someone is looking, whether it is at the eyes, nose, eyebrow, mouth, etc.) Therefore, instead of asking how an individual scans the features of a face, one can use eye tracking to ask the question of whether or not faces attract attention in the first place. While it is of course important to understand how one views the various internal and external features of a face, equally important, if not more relevant to ASD, is to also examine the *selection* of faces in the context of competing stimuli (e.g., background, objects, etc.).

Along with the work by Klin et al. (2002), some other studies have attempted to mirror the complexity of real social environments by presenting scenes depicting people within natural environments surrounded by competing visual stimuli. Here, one can ask whether individuals with ASD show attentional selection for faces, when faced with competing choices of what to attend to within a scene. Research measuring eye movements in NT adults viewing social and nonsocial scenes has found that they show a strong attentional preference for social scenes (Fletcher-Watson, Findlay, Leekam, & Benson, 2008). Fletcher-Watson et al. (2009) replicated this initial study with a group of high functioning ASD (HFA) and NT adolescents and adults. Participants were shown pairs of scenes, each consisting of a “person-present” scene and a “person-absent” scene. The results failed to show an overall group difference in attentional preference, with both groups showing a strong bias to look at the person-present scene and particularly the person in the scene. However, while the NT group exhibited this bias in the first fixation, the ASD group failed to show a preference for the social element of the scene in the first fixation, suggesting reduced social attentional priority. Thus, while faces still attracted the attention of individuals with ASD, faces were less salient, as indicated by the lack of social attentional bias in the first fixation. How this reduced saliency plays out in real-world contexts and affects social and emotional comprehension remains less clear. Additionally, while some of these above described effects appear to be subtle in adults, preference for nonsocial stimuli may be more pronounced in younger children with ASD (Klin, Lin, Gorrindo, Ramsay, & Jones, 2009; Pierce, Conant, Hazin, Stoner, & Desmond, 2011), suggesting differences in patterns of visual attention and preference may manifest in different ways over development. This suggests differences in patterns of visual attention and preference manifest in different ways across development, with the effects being more subtle but still detectable in older individuals with ASD.

Stimulus valence may also interact with attention in adults with HFA. There is an evolutionary advantage to rapidly processing threatening stimuli, as they provide relevant warning signs of imminent danger. They elicit an immediate fear response and direct attention toward the source of danger (Vuilleumier & Schwartz, 2001). This process has been termed the “threat detection advantage” (Eastwood, Smilek, & Merikle, 2001). Not surprisingly, attentional priority for threatening faces is evident beginning in childhood in typical development (Santos, Silva, Rosset, & Deruelle, 2010). Santos and colleagues (2012) measured spontaneous orienting behaviors in individuals with ASD to investigate whether they also show a threat detection advantage. Adolescents and adult participants were presented with pairs of emotional, either negative or positive, and neutral social scenes (i.e., positive emotional–neutral, negative emotional–neutral, or neutral–neutral pairs). While the NT groups showed a strong preference and displayed longer first fixation durations for the negative scenes over the positive or neutral scenes, the study failed to reveal initial preferential orienting toward socially threatening scenes in the HFA group. However, the HFA group did adapt their viewing behavior over time and reached typical patterns at later stages of viewing, reflected by a greater total number of fixations on the negative emotional scene in comparison, similar to the patterns observed in the NT group.

It is worth emphasizing that both the Santos et al. (2012) and the Fletcher-Watson et al. (2008) studies found no overall group differences between ASD and NT when using average fixation duration as a measure of social attention. The differences in both studies are far subtler than the studies discussed previously, in that the differences only emerge in the first few moments following stimulus onset. Despite the differences being short lived, these still may translate into social difficulties in the real world—perhaps an individual with ASD misses a fleeting emotional expression, or misses a quick glance indicative of a person's interest. Given that social information in the real world can be very brief, any impairment in initially orienting to or paying attention to these social cues could have debilitating effects on one's success in social interactions. However, how these small differences in social attention relate to real-world social impairment has yet to be demonstrated.

Findings that demonstrate atypical social orientation as presented thus far may seem robust and largely consistent. However, they have not gone unchallenged, and replication across studies has been an issue. For example, van der Geest and colleagues (2002a) were not able to replicate the findings of Pelphrey et al. (2002). HFA and typically developing children matched on age and IQ were shown faces depicting basic emotions while eye movements were recorded. Unlike previously discussed findings, the results showed both groups behaving very similarly, fixating on the eye and mouth regions longer than other parts of the face, with the first fixations of both groups directed to the eyes. In another study, children with ASD also showed similar preferences to human figures over objects in a complex cartoon scene (van der Geest, Kemner, Verbaten, & Van Engeland, 2002b). Furthermore, Fletcher-Watson et al. (2008) found no evidence of overall group differences in fixation time on the eyes between young adults with ASD and controls. And, individuals with ASD have been found to be just as effective in detecting nonsocial changes as NT controls in a change blindness task (Fletcher-Watson et al., 2006). It was hypothesized that NT individuals would show reduced reaction times in detecting changes in eye-gaze direction given their superior attentional bias toward social information. Contrary to their hypotheses, however, individuals with ASD showed very similar abilities in detecting eye-gaze changes as controls.

What conclusions can we draw about social attention in ASD based on these discrepancies? There are a number of possibilities here, including differences in participant demographics, differences in the nature of the task and its demands, and differences in the nature of the stimuli themselves. For example, while the participants in the Pelphrey et al. (2002) and Klin et al. (2002) studies consisted of male adolescents and young adults (mean ages of 25.2 and 15.4 years, respectively), the two van der Geest et al. (2002a, b) studies tested school-aged male children (mean age of 10.6 years). It is possible that discrepant findings could indicate developmental changes in gaze behavior, not only in individuals with ASD but also in NT individuals. It has been demonstrated, for instance, that qualitative differences in patterns of attention can emerge during development. For example, Nakano et al. (2010) found that typical infants prefer to watch mouths over eyes during speech, but that this preference reverses with development (see also Schulz et al., Chap. 6, this volume). The same study also found the time spent viewing the mouth relative to face to be significantly longer in NT children compared with NT adults and adults with ASD, but no differences were found between NT and children with ASD, suggesting these differences only emerge later in development. In addition, control participants showed more standardized gaze behaviors, more likely exhibiting similar gaze patterns, compared with ASD participants. Given the fact that the studies discussed above had relatively small sample sizes, the results may also be strongly influenced by the heterogeneity in gaze behaviors among individuals with ASD.

In addition to differences in subject characteristics, some of the studies discussed used static photos of faces (Pelphrey et al., 2002; van der Geest et al., 2002a), while others used complex and/or dynamic stimuli containing multiple people (Klin et al., 2002), or static cartoon depictions of people and objects as stimuli (van der Geest et al., 2002b) to test differences in social attention. It is possible that differences in the type of stimuli used contribute to these discrepant findings across studies. To address this possibility directly, Speer and colleagues (2007) compared the effects of stimulus content and stimulus type on gaze patterns. Each ASD and NT participant was shown four different types of stimuli: social dynamic, social static, isolated dynamic, and isolated static. The social dynamic stimuli consisted of video clips of highly emotional interactions among two or more characters. The isolated dynamic stimuli were also videos, but only depicted one individual. The social static and isolated static stimuli were static images of either two or more people, or just one person, respectively. Interestingly, group differences were only statistically different between the two groups in the social dynamic condition. Though it seems that statistical power issues may account for the lack of differences in these other conditions, individuals with ASD spent less time looking at the eyes than the NT group and more time looking at the body, replicating previous results (Klin et al., 2002). The authors concluded that differences in social orienting and face processing associated with ASD might at least be partially dependent on the stimuli being both realistic and social, since when either one variable was missing, the ASD group did not perform significantly differently from those in the control group. However, it is worth raising the caution here that it seems that statistical power issues could have accounted for lack of differences in these other conditions. A more recent study also found that spontaneous allocation of attention to faces, and more specifically the eyes, is influenced by the way in which the faces are presented (Hanley, McPhillips, Mulhern, & Riby, 2013). This study varied stimuli based on the degree of social context presented, whether faces were presented in isolation or within a social scene, as well as whether the social interaction depicted was acted or naturally occurring. Their results demonstrated that both adolescent and young adults with ASD and NT controls attend similarly to isolated faces. However, when faces were presented within a social context, with additional information competing for attention, ASD participants showed abnormally reduced fixations to the eyes, while the NT group prioritized the visual information from the eyes. Therefore, atypicalities in the ASD group were more evident when viewing more visually and socially complex images, highlighting ecological validity as an important experimental parameter to consider in research involving this population.

7.2.2 Attention to Eye Gaze in ASD

The studies discussed thus far highlight the importance of the eyes in faces, and how salient they seem to be to NT individuals compared to those with ASD (Klin et al., 2002; Pelphrey et al., 2002). Eyes, in addition to providing valuable information about the target's emotions or identity, can also help identify another person's intentions or alert of potential threats in our environment (Ristic et al., 2005; Hadjikhani, Hoge, Snyder, & de Gelder, 2008). For instance, eyes making direct eye contact might signal anything from aggression to romantic interest, while eyes directed toward a particular location might indicate the focus of a person's attention and signal that something is of interest in that location. Given the communicative and social importance of the direction of one's eye gaze, it comes as no surprise that NT individuals are highly attentive and sensitive to changes in gaze direction. Following one's direction of gaze (i.e., gaze following) can be a largely automatic and spontaneous process. For example, 9-month-old infants are sensitive to the relationship between gaze direction and location of objects, looking longer at a face that gazes toward an object compared with those looking in the opposite direction (Senju, Csibra, & Johnson, 2008). In fact, as discussed in other chapters (Bertenthal & Boyer, Chap. 2, this volume), gaze following emerges at the earliest stages of development (2–5-day-old newborns) (Farroni, Massaccesi, Pividori, & Johnson, 2004).

Given the findings that individuals with ASD exhibit reduced fixation on the eyes, one might predict that these atypicalities translate into difficulties in utilizing gaze information in the typical manner (see Frischen et al., 2007 for a review on visual attention to gaze in NT individuals). Being able to follow the gaze of an individual is thought to be a foundational behavior for a number of important domains of functioning. For example, gaze following behaviors at 10–11 months are strongly and positively correlated with subsequent language development at 18 months in typically developing infants (Brooks & Meltzoff, 2005). Furthermore, joint attention skills at 20 months have been positively correlated with the ability to understand the minds of others (i.e., mentalizing or theory of mind (Baron-Cohen, 1995)) at 44 months in typically developing infants (Charman et al., 2000). Joint attention, language, social communication, and theory of mind are all domains that are affected in ASD (American Psychiatric Association, 2013; Baron-Cohen, Leslie, & Frith, 1985; Happé, 1995), further leading researchers to suspect altered attention to, and utilization of, eye gaze of others in ASD.

Many researchers have argued that children with ASD indeed show deficits in the processing of gaze. For example, children diagnosed with ASD show reduced gaze-monitoring (i.e., looking in the same direction that an adult is looking in) at

18 months of age (Baron-Cohen et al., 1996) and show impairments in joint attention (Leekam, Baron-Cohen, Perrett, Milders, & Brown, 1997), suggesting a relative insensitivity to direction of gaze. Despite these early differences, other studies have found that children with ASD do show reflexive orienting to gaze direction (Swettenham, Condie, Campbell, Milne, & Coleman, 2003; Chawarska, Klin, & Volkmar, 2003). Using a modified spatial cueing paradigm (Posner, Snyder, & Davidson, 1980), Swettenham et al. (2003) asked HFA and chronological age-matched typically developing (TD) children to press a key as quickly as possible when they detected a target on the screen. Prior to the target presentation, participants would see a person's face whose eyes would look either to the left or to the right. The target would then appear randomly on either side of the face, congruent or incongruent to the gaze direction of the person. Despite the fact that the gaze direction did not predict the target's location and that participants were explicitly told this, neither group was able to ignore the gaze cues, as demonstrated through faster responding to the congruent cues compared with the incongruent cues. Chawarska et al. (2003) found comparable results in an experiment using a similar paradigm in 2-year-old children. Both toddlers with ASD and age-matched TD children exhibited shortened saccadic reaction times to the congruent target, suggesting reflexive eye movements brought on by the direction cue of the person's gaze.

However, there is one important consideration to keep in mind when interpreting these findings—the stimuli used in these studies included faces without bodies or any other visual information in the background competing for the viewer's attention. This situation is vastly different from social stimuli that individuals normally encounter, which are embedded within complex, dynamic, multimodal, and less predictable environments. Given the data suggesting individuals with ASD tend to increasingly display abnormal gaze patterns when viewing more ecologically valid stimuli (Speer et al., 2007; Hanley et al., 2013), it is possible we may discover differences between groups as we move away from isolated social stimuli.

To address this possibility, Freeth et al. (2010) investigated whether fixation patterns of individuals with ASD are affected in the same manner as NT controls by the eye-gaze direction of an observed person when viewing a complex social scene. Adolescents with HFA and adults and NT controls, matched on IQ, viewed photos of an everyday setting containing one person and multiple objects. The person in the photo looked either straight ahead or at an object on the opposite side of the scene. The objects present in the photos were located either at the exact location of gaze, on the same side of the photo as the gaze but not at its actual location, or on the opposite direction of the gaze. Similar to previous findings (Fletcher-Watson et al., 2009), no overall group differences were found in the proportion of time spent fixating on the face compared with objects or bodies. However, faces seemed to be more highly prioritized by the NT group compared with ASD, as indicated by quicker first fixations to the face when the scene was initially presented. In contrast, individuals with ASD were faster to first fixate on objects, but later adjusted their gaze to look at faces. Both groups were cued by the gaze direction of the person, replicating studies of younger children and toddlers (Swettenham et al., 2003; Chawarska et al., 2003).

However, another way of looking at the influence of gaze direction of visual attention is also to examine the consequences of such gaze, not just on how viewers saccade toward the object, but how they prioritize that object once fixated. In the same study by Freeth and colleagues (2010), NT individuals showed an immediate increase in fixation duration on the object that the person in the photo was looking at, while this pattern was not observed in the ASD group. This result suggests that while adolescents with HFA are able to follow gaze direction, the significance of the gaze cue in influencing their processing of the scene is different. Riby et al. (2013) further tested this idea by additionally asking participants to explicitly identify the object being gazed upon. Using a similar paradigm, ASD and NT individuals looked at pictures including one actor gazing at a target object among three different possible objects, and were asked to name the target object. Compared with a condition when participants freely viewed the stimuli, individuals with ASD increased their gaze at the person's face and eyes when asked to identify the target, indicating that they understood where to look for this information. However, while the NT group shifted their attention from the face to the correct target, the ASD group failed to follow the gaze of the person and continued to look at implausible objects, rather than the target, which resulted in more incorrect responses. These data suggest that the ability to use gaze reflexively is spared when individuals with ASD are not required to select gaze information within very simplified viewing situations. However, the deficit becomes clearer when gaze is embedded in a complex scene, as reflected by the inability to effectively use the information conveyed by gaze direction.

7.2.3 Additional Evidence for Social Attention Abnormalities in ASD

Eye tracking is an incredibly versatile methodological tool to study social attention in ASD, as evidenced by the numerous studies and diverse findings across differing experimental paradigms. However, there are other behavioral measures of social attention that have provided further evidence for disruption in social attention and information processing among older children and adults with ASD. One paradigm in particular that has been widely used to study attentional differences in ASD is the change detection paradigm. In a change detection study, participants are presented with pairs of images that are nearly identical, with the exception of one part of the scene that is altered (e.g., color, presence or absence of an object, gaze direction, etc.) (Simons, 2000). The change is made especially difficult to detect by presenting the images in temporal succession, separated by a brief blank screen, rather than showing them both simultaneously (Rensink, O'Reagan, & Clark, 1997). This paradigm provides additional information beyond what eye tracking can show since it evaluates not only where, but also what specific features the participant is attending to (Simons & Rensick, 2005). For instance, an individual may be looking at an object, but not processing its color, size, orientation, smoothness, and so on. In the social realm, an individual may be looking at a face, but perhaps does not notice the eye-gaze direction, facial expression, identity, etc. Thus, compared with eye tracking, change blindness paradigms can, in certain cases, be better suited to address some questions regarding social (and nonsocial) attention.

As one example, Kikuchi et al. (2009) tested social and nonsocial change detection in ASD and TD school-aged children who were presented with pairs of photographs depicting multiple faces and objects in a naturalistic setting. A change was introduced in one of the photographs, replacing either a face or object within the image, and participants were asked to press a key when the change was detected. A previous study had shown a social change advantage in TD children (Humphreys, Hodsoll, & Campbell, 2005). However, given the eye tracking data pointing to reduced attention to faces in ASD, it was hypothesized the ASD group would not show this advantage. This was borne out in the results: TD individuals detected changes to faces faster than changes to objects, while children with ASD did not.

It is of course expected that faces would not be preferentially processed if attention and gaze were not preferentially allocated to them. However, NT adults have additionally been shown to have difficulties ignoring faces, suggesting that faces are not only processed preferentially, but also perhaps automatically, in a mandatory fashion (Farah, Wilson, Drain, & Tanaka, 1995). Remington, Campbell, & Swettenham (2012) examined the degree to which faces capture attention in ASD and NT adults by simultaneously imposing a perceptual load. The strong, automatic attentional bias for faces in NT individuals would predict that they would continue to be distracted by faces despite the increased perceptual load, whereas individuals with ASD would not show signs of interference. Participants were instructed to decide whether a name shown on the screen was male or female. To manipulate the perceptual load, the name was presented alone or among a list of a varying number of distractor nonwords. Additionally, a face was presented next to the list of words, which was either congruent or incongruent (same or opposite gender as the target name). Participants were explicitly told to ignore the faces. If the faces are being attended to, one would expect them to interfere with the name task, as indicated by a faster reaction time for congruent versus incongruent trials. Regardless of perceptual load, the NT group showed congruency effects, suggesting they were unable to ignore the faces despite their irrelevance to the task at hand. While this effect was evident during lower perceptual load conditions in the ASD group, it was not found during higher load conditions. The differing congruency effect with regard to load in ASD is intriguing, as it indicates that individuals with ASD only processed the faces when task demands were low. In other words, the face processing bias seems comparatively weak in ASD, especially in certain situations, though not necessarily absent.

In addition to attention to faces in general, evidence of altered attention to eye gaze in ASD was found in a recent study by Pellicano, Rhodes, and Calder

(2013). This study examined the ability of the gaze perception system to adapt to prolonged exposure to a particular gaze direction. A similar study conducted with NT adults showed that prolonged exposure to faces with eyes averted 25° leftward resulted in a tendency to judge subsequent faces with leftward gaze as looking forward (Jenkins, Beaver, & Calder, 2006), which is referred to as a perceptual aftereffect (i.e., distortions following exposure to a stimulus). Children with ASD and NT controls (9–14 years of age) were asked to first complete a gaze acuity task where they categorized the direction of gaze of faces with eyes averted 10° or 5° left, straight ahead, and 10° or 5° right. Next during the adaptation phase, participants observed a series of faces showing gaze averted 25° in a single direction (left or right) for 1.5 minutes. During the post-adaptation phase, participants completed a second gaze acuity task, with the adapting image showing gaze in the adapted direction preceding the test image to maintain adaptation effects. Controls displayed an increased tendency to perceive gazed averted in the adapted direction as looking straight-ahead, replicating previous findings (Jenkins et al., 2006). While the ASD group also showed these aftereffects, the effects were significantly reduced relative to controls, which the authors interpret to suggest an attenuated calibration of others' gaze. Furthermore, the ASD group showed reduced accuracy in categorizing subtle deviations in gaze direction compared with controls during the pre-adaptation phase, and accuracy was related to the magnitude of gaze aftereffects in ASD. The results suggest not only subtle atypicalities in gaze perception in general, but also that the mechanisms underlying gaze processing may be less flexible in ASD.

7.3 Functional Consequences of Aberrant Social Attention in ASD

So far we have focused on behavioral studies characterizing atypical social attention among individuals with ASD. While there are some discrepancies in findings (e.g., fixation time to mouth versus eyes), generally individuals with ASD appear to show differences in attention to various social stimuli. But why does this matter? There is an important question that we have not yet addressed: Namely, how do abnormalities or deficiencies of social attention contribute to the ASD phenotype? In other words, what are the functional consequences? As described earlier, it has been hypothesized that a disruption of early social attentional mechanisms constitutes a primary deficit in ASD, with detrimental downstream consequences for social and language development (Chevallier et al., 2012). Thus, one might expect to see reduced or abnormal attention to faces together with impaired processing of faces. Below, we discuss separately how individuals with ASD process two types of social information; namely, facial identity and emotional expression.

When taking verbal IQ into account, individuals with ASD are relatively able to recognize highly familiar faces (Wilson, Pascalis, & Blades, 2007). Impairment in face recognition becomes more evident when remembering and discriminating unfamiliar faces (Boucher & Lewis, 1992; Klin et al., 1999; Blair, Frith, Smith, Abell, & Cipolotti, 2002). Blair et al. (2002), for example, examined the facial recognition memory of adults with ASD and two control groups matched on either age or verbal IQ. Participants were administered a standardized memory recognition test, involving previously unfamiliar pictures of faces and buildings. The ASD group exhibited significantly poorer visual recognition memory for unknown faces compared with both comparison groups. Yet, the ASD group showed intact memory for buildings, suggesting a domain-specific memory impairment for faces. Findings of a circumscribed facial recognition impairment for unfamiliar faces have also been observed across ages, not attributable to general cognitive deficits, memory deficits, or task demands (Klin et al., 1999; Boucher & Lewis, 1992).

Many have also reported reduced accuracy in identifying emotions in adults with ASD (Ashwin, Chapman, Colle, & Baron-Cohen, 2006; Wallace, Coleman, & Bailey, 2008; Corden et al., 2008; Harms, Martin, & Wallace, 2010; Kennedy & Adolphs, 2012). Adults with HFA when compared with matched controls performed significantly worse overall in a task involving the recognition of basic emotions (happiness, fearful, disgust, anger, sadness, and surprise) (Ashwin et al., 2006). In this particular study, the emotion recognition deficits, however, were limited to negative emotions—fear, disgust, anger, and sadness—with no group differences in identifying happiness, surprise, or neutral expressions. These results were also replicated by Wallace, Coleman, and Bailey (2008), who found that adults with HFA showed a general impairment in recognizing basic expressions, with a particular impairment in recognizing fear, disgust, and sadness. This group further examined emotion recognition by gradually revealing the number of facial features available to the participant. Here, the participants viewed either the mouth or eyes alone, a nose, or all three features (eyes, nose, and mouth) during the task. While the NT group was significantly more accurate in recognizing fear from the eyes than the mouth, the ASD group showed no advantage in the eyes-only condition, frequently misidentifying fear as anger.

Eye tracking data simultaneously collected during a similar emotion recognition task further revealed the importance of the eyes in the recognition of fear in particular (Corden et al., 2008). This study found adults with ASD to display difficulties in recognizing fearful and sad faces, with a trend toward an effect for angry faces. The ASD group generally spent less time fixating the eye region compared with controls, consistent with the previous findings reviewed earlier (Klin et al., 2002; Pelphrey et al., 2002). The degree of fear recognition impairment in the ASD group was also predicted by their time fixating away from the eyes throughout the experiment. In other words, time spent fixating on the eyes was positively correlated with fear recognition accuracy.

Adding further support for different strategies of emotion recognition, Spezio et al. (2007a) found individuals with ASD gaze at, and utilize, information from faces differently from controls. This study used the “Bubbles” method (Gosselin

& Schyns, 2001) to further understand the relationship between how people use information from different regions of the face when making emotion judgments. With this method, faces are largely masked except the parts of the face underlying the location of randomly placed and different sized circles (i.e., Bubbles), with each size of bubble corresponding to a different spatial frequency. The participant is then shown this degraded, bubbled image and the viewer is instructed to make a judgment based on what they see. Using reverse correlation, one can then determine which parts of the image were shown when participants were able to make a correct compared with an incorrect response in order to determine what information was used for successful task performance. Spezio et al. (2007a) tested adults with HFA and controls matched on IQ and revealed that individuals with ASD are strongly distinguishable from controls in the features they rely on while making emotion judgments. The HFA group utilized the information from the eye regions significantly less while also showing a marked increased reliance on information from the mouth compared with controls. This difference in strategy is particularly interesting given that, in this study, the groups showed no differences in overall performance in emotion recognition.

This was not the only study, however, to fail to find performance differences in recognizing facial expressions in ASD—in fact, many other studies have also failed to find such differences in the recognition of basic emotions in both children and adults with ASD (Baron-Cohen, Spitz, & Cross, 1993; Grossman, Klin, Carter, & Volkmar, 2000; Adolphs, Sears, & Piven 2001). Other studies have found that even if such differences exist, they can be somewhat subtle and require more sensitive methods and measures to detect any abnormality (Kennedy & Adolphs, 2012). In particular, it seems that discrepancies across studies may at least partially depend on task demands, with the lack of effects reflecting possible ceiling effects. Grossman et al. (2000), for example, found similar performance (both in accuracy and in reaction time) between HFA and NT adults when participants were simply asked to identify the emotion depicted in a photograph. However, differences were observed in these same participants during a more complex task where they viewed emotional faces paired with an emotional label that either matched the expression (e.g., happy face with the word "happy") or mismatched (e.g., happy face with the word "afraid") and were asked to identify the emotion of the person. In this condition, only the ASD group's accuracy was negatively affected by the mismatched verbal label. These results provide evidence for a qualitative difference in the processing of emotions by individuals with ASD.

Clark, Winkielman, & McIntosh (2008) utilized a different method to increase task demands—namely, by reducing the exposure duration of the face stimuli dramatically. HFA and NT adolescents and adults were briefly shown pairs of emotional faces, neutral faces, and non-faces. In the Emotion condition, participants decided which face was happy or angry, in the Neutral condition they decided on the gender, and in the Non-Face condition they identified which image was an object or an animal. The stimuli were only presented for 15 ms or 30 ms, which previous studies have shown is long enough for NT adults to extract valence of faces (e.g., Murphy & Zajonc, 1993). While both groups performed similarly in the Neutral and Non-Face conditions, the ASD group performed worse during the Emotion condition, suggesting a specific impairment in the ability to rapidly extract emotion information from faces.

Together, these findings point to a possibility that higher-functioning individuals with ASD perhaps utilize compensatory mechanisms to decode emotions—one that is less automatic and slower. When faced with more demanding situations, these compensatory strategies fail, thus exposing their impairments. This may also explain the discrepancy researchers often observe—surprisingly intact performance on various laboratory tests assessing emotion perception, but clear deficits in real-world interactions. Given the studies reviewed above, one explanation may be that real-world interactions qualitatively differ from typical laboratory tests in a number of ways; for instance, the real world is highly dynamic, less structured and less predictable, more interactive (i.e., may require a response), and highly context dependent, with fleeting social cues, etc. In essence, identifying facial expressions in the real world is perhaps more similar in some ways to the more demanding experiments described above, precisely where the deficits in individuals with ASD become more apparent.

Furthermore, assessing emotion recognition abilities in ASD should extend beyond the study of the basic emotions, because our repertoire of generating and decoding facial expressions extends well beyond the basic emotions (happy, sad, fear, surprised, disgust, anger, contempt, along with neutral). Often times we are faced with the need to identify complex expressions that may reflect more of a mental state (e.g., troubled) and/or social emotion (e.g., embarrassment, flirtatiousness), both of which are subtler than the basic emotions. One widely used task is the "Reading the Mind in the Eyes" task (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001), where a participant is shown a picture of a person's eyes and asked to identify the social emotion that best describes their perceived mental state (e.g., annoyed, ashamed, distrustful, and interested). Multiple studies utilizing this task have shown individuals with ASD perform worse than matched controls (Baron-Cohen et al., 2001; Kaland, Callesen, Møller-Nielsen, Mortensen, Smith, 2008; Holt et al., 2014; Schuwerk, Vuori, & Sodian, 2014). More recently, tasks using complex videos rather than static, isolated images of eyes have been used to assess the recognition of complex social emotions in ASD (Dziobek et al., 2006; Golan, Baron-Cohen, Hill, & Golan, 2006). Golan et al. (2006) had adults with HFA and matched controls view clips of videos depicting dramatic emotional interactions between multiple people and asked participants to identify the complex emotion (e.g., smugness, awkwardness) of a character in the scene. Consistent with previous studies utilizing static images, the ASD group performed significantly worse than controls.

Taken together, these results suggest that while recognition of basic emotions may be preserved in some individuals with ASD, adults with ASD may continue to exhibit difficulties with recognizing more subtle and complex social emotions (see Harms et al., 2010 for review; Golan & Baron-Cohen, 2006).

7.4 Neural Correlates of Altered Social Attention

The broad range of behaviors and affected domains that characterize ASD suggests there perhaps is a diverse set of neural systems that is responsible for the ASD behavioral phenotype (Schultz, 2005; Amaral, Schumann, & Nordahl, 2008). Beyond visual attention differences to social stimuli, individuals with ASD, not surprisingly, have difficulties making judgments based on social stimuli (e.g., face processing, theory of mind). It is not difficult to see that the ability to efficiently and accurately make various social judgments is crucial to successfully function in our vastly social world. In particular, the fundamental role of face processing in guiding social interactions has led to the initial hypothesis that abnormalities in the neural circuitry involved in face processing contribute to social dysfunction in ASD (Schultz et al., 2003). Within the social attentional domain specifically, researchers have studied multiple regions that may be involved in the atypical behavioral findings we have discussed. In this section we review the current literature examining the possible neural correlates of atypical social attention in ASD, with a focus on three brain regions known to play important roles in processing facial identity, facial expressions, and gaze direction.

However, we should at the outset make it very explicit that although we are focusing on single brain regions in the following sections, this is largely due to the fact that until recently, research on ASD (and in cognitive neuroscience more generally) has been very brain region- and location-centric (Sporns, 2011). Yet, it is undeniable that any single brain region acts within a larger network context, and its specialization comes from the input it receives, the local computations it performs, and the output it sends—in other words, a brain region does not act alone and cannot be fully understood independently from other regions. Yet, the majority of research on autism to date that has examined neural correlates of social attention and emotional processing has focused on a few select regions that have been implicated in these processes. Methods to describe and make sense of network-level properties are being actively and rapidly developed (e.g., Bullmore and Sporns, 2009; Sporns, 2013; Bassett & Lynall, 2013), while at the same time behavioral links to network-level functioning are still quite sparse. Therefore, in the section that follows, we focus on the fusiform face area (FFA), the amygdala, and the superior temporal sulcus (STS), while we fully acknowledge the essential role that brain networks will play in ultimately understanding complex social behaviors and psychopathology (e.g., Uddin, Supekar, & Menon, 2010; Kennedy & Adolphs, 2012; Happé & Frith, 2014) (Fig. 7.3).

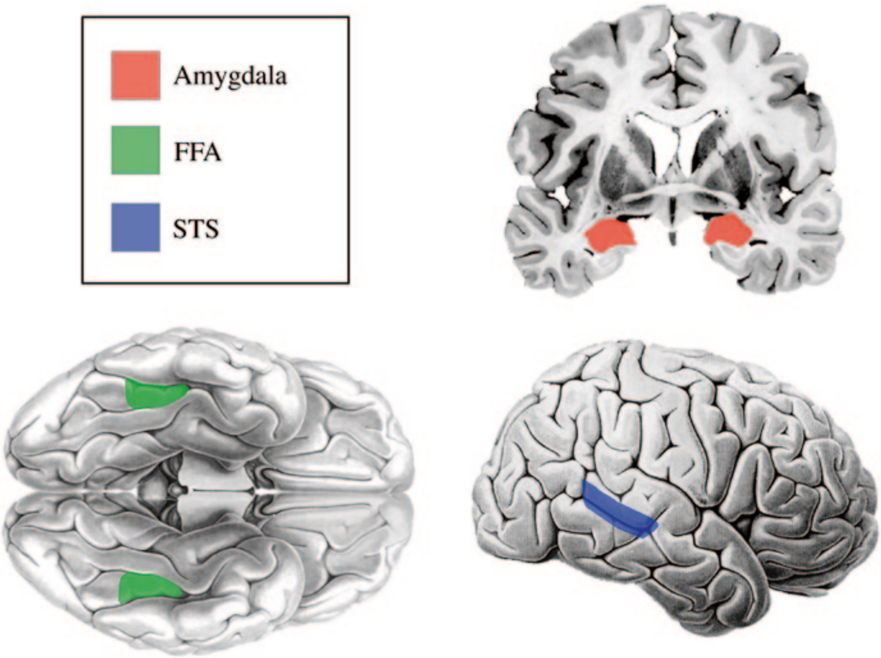

Fig. 7.3 *Three brain regions associated with atypical social attention in ASD.* Amygdala *(red)*, fusiform face area (FFA; *green)*, superior temporal sulcus (STS; *blue)*. Adapted from Kennedy and Adolphs (2012). Reprinted with permission

7.4.1 Fusiform Face Area (FFA)

Functional magnetic resonance (fMRI) studies with NT controls have identified a small region of the fusiform gyrus (FG) that is more strongly activated in response to face stimuli than other visual stimuli (Puce, Allison, Gore, & McCarthy, 1995; Kanwisher et al., 1997; Haxby, Hoffman and Gobbini, 2002). This area is known as the fusiform face area (FFA), and is identified functionally by contrasting FG activation when subjects are viewing faces versus non-face objects (e.g., houses). Its putative role in face perception (Kanwisher et al., 1997), has been further supported by convergent studies showing that lesions in this area result in prosopagnosia, or the inability to recognize faces (Damasio, Tranel and Damasio, 1990). However, whether or not the FFA is truly face-specific has been challenged by Gauthier and Nelson (2001), who argued that the region is responsive to categories of objects with which one has visual expertise. Support for this comes from studies showing this region to be engaged during bird or car viewing in individuals who are bird or car experts (Gauthier, Skudlarski, Gore and Anderson, 2000). This suggests that the functional specialization of the FFA may have evolved to discriminate between individual objects within a broader category, which are most likely faces for the majority of individuals. FFA activation in NT individuals is automatic in response to any face regardless of expression (Winston, Henson, Fine-Goulden, & Dolan, 2004) and lesions to this area do not appear to cause deficits in emotional expression recognition (Damasio et al., 1990), suggesting a specific role in processing facial identity. Regardless of whether the FFA is specialized for faces uniquely or more broadly sensitive to category expertise, it is undeniable that the FFA is a region critically involved in face processing in NT individuals. Given the abnormal gaze patterns to faces in ASD and difficulties with facial identity recognition, the FFA has been widely studied as one possible neural substrate that may be responsible for abnormal social attention (see Schultz, 2005 for review).

Schultz et al. (2000) conducted the first fMRI study to test whether ASD involves abnormal neural activation during face processing. First, regions of interest (ROIs) that activated in response to viewing objects and faces were identified in the right inferior temporal gyrus (ITG) and FFA, respectively, in a separate group of NT controls. The patterns of activations in adults with HFA and IQ-matched controls in these brain regions were then compared while participants were asked to decide if two pictures simultaneously presented were the same or different from each other. The pairs of stimuli included neutral faces (without hair or ears), various objects (e.g., cars, boats, chairs), or nonsense patterns. They found differences in the pattern of brain activation during face discrimination between ASD and NT groups. Specifically, consistent with prior studies with NT adults (Kanwisher et al., 1997; Haxby et al., 2002), the NT group showed activation in the right FFA during face discrimination, but this pattern was not seen in the ASD group. However, the ASD group showed abnormally increased activity in the ITG during face discrimination compared with the NT group, an area that was most strongly associated with object discrimination in NT controls. The authors suggested that this might mean that the ASD group processed faces more like objects, though such an interpretation based on reverse inference has to be considered with due caution. Thus, the results indicated that individuals with ASD exhibited not only reduced activity to faces in the expected brain region (i.e., FFA/FG), but also increased activation in an unexpected location (i.e., ITG) that is more specialized for processing objects. This finding is important because it demonstrates not just hypoactivation, but an altered pattern of responding.

Pierce et al. (2001) reported similar findings: HFA and NT adults matched on gender and age performed a face perception task, pressing a button in response to female faces, alternating with a shape perception task, during fMRI acquisition. The investigators chose three cortical ROIs: FFA, ITG, and the middle temporal gyrus (MTG), which has also been previously shown to consistently respond to objects more than faces (Allison et al., 1994). The ASD group did not differ from the NT group in terms of accuracy and response times on either face or object perception task. However, the ASD group showed either abnormally weak or no activation in the FFA in response to faces. But, this did not mean that the brain was simply unresponsive to faces. Rather, the ASD subjects in this study exhibited unique and non-overlapping functional maps in response to faces, some showing maximal response to faces in the frontal cortex, temporal cortex, occipital cortex, or the cerebellum.

The lack of spatial overlap between subjects resulted in an overall image showing no positive functional activity, suggesting individuals with ASD may process faces via unique neural circuitry. Hypoactivation of the FFA was subsequently replicated by multiple studies (e.g., Critchley et al., 2000; Hall, Szechtman, & Nahmias, 2003; Wang, Dapretto, Hariri, Sigman, & Bookheimer, 2004) and together these findings have led to suggestions that individuals with ASD fail to develop cortical face specialization, possibly due to reduced social interest or attentional deficits to faces (Pierce et al., 2001; Grelotti, Gauthier, & Schultz, 2002). Yet, we should keep in mind that ASD individuals do not exhibit profound face perception deficits to the degree that is found in prosopagnosia—i.e., most individuals with ASD are not prosopagnosic. So, what might these neural differences mean?

Neural responses to faces in NT individuals have also been found to be dependent on factors such as familiarity and emotional valence. For example, FFA activity is greater in NT individuals when looking at familiar faces compared with non-familiar faces (Henson et al., 2003), and greater in response to emotional faces than neutral faces (Vuilleumier, Armony, Driver, & Dolan 2001). To study if functional activation in the FFA is modulated by familiarity of faces, Pierce et al. (2004) presented ASD and NT adolescents and adults matched on gender and age with familiar faces (i.e., family and friends) and faces of strangers during fMRI data acquisition. The results were consistent with previous studies of NT individuals (Vuilleumier et al., 2001; Winston et al., 2004) showing greater FFA activation in response to familiar faces, compared with faces of strangers. And, while the NT group did show quantitatively greater FFA activation to unfamiliar faces than the ASD group, these differences were not statistically significant, in contrast with previous studies (Schultz et al., 2000; Pierce et al., 2001). The authors speculate that these findings indicate an enhanced motivation overall to attend to the faces due to familiar faces being dispersed throughout the task. Thus, previous findings of FFA hypoactivation may not reflect a true neurofunctional abnormality, but rather a social attentional difference that may be more apparent in some tasks (Schultz et al., 2000; Pierce et al., 2001), but not others (Pierce et al., 2004).

Given the eye tracking findings discussed in the previous section, one possibility is that the abnormalities in the way individuals with ASD visually attend to faces (Klin et al., 2002; Pelphrey et al., 2002) may very well be contributing to abnormal FFA activity. Hadjikhani et al. (2004) assessed cortical activation in response to face and non-face objects in ASD and NT adults matched on age and IQ. Participants were shown pictures of faces, objects, and scrambled pictures. Each stimulus had a red fixation cross in the center and participants were instructed to focus on the fixation cross to maximize the possibility that they would attend to the central area of the face. Individuals with ASD showed bilateral FFA, as well as inferior occipital gyri (IOG) activation in response to faces, similar to controls. Another area of the FG, medial to the FFA, which is referred as the fusiform object area (FOA) was activated in response to objects in both groups. In contrast to previously discussed studies (Schultz et al., 2000; Pierce et al., 2001) there was no evidence of areas abnormally recruited to process faces in the ASD participants. These results suggest that findings of FFA hypoactivation in individuals with ASD may reflect a failure to attend appropriately to faces rather than a lack of cortical specialization. Introducing a fixation cross as well as instructions to maintain focus on it throughout scanning may have facilitated the participants' attending to the core features of the face. In addition, this study used passive viewing without an active task (i.e., same/different and gender discrimination), which the authors suggest may have prevented participants from using particular strategies to support task performance (e.g., focusing on peripheral features of the face in their efforts to discriminate faces). However, while this study was suggestive of gaze differences accounting for FFA hypoactivation in ASD, it did not directly test this hypothesis.

A subsequent study by Dalton et al. (2005) directly examined the hypothesized relationship between patterns of gaze fixation and brain activation during face processing, predicting that diminished gaze to the eye regions of faces may underlie FFA hypoactivation. ASD and NT adolescents and adults matched on age participated in two tasks during fMRI acquisition, a facial emotion discrimination task and a facial identity recognition task (familiar vs. unfamiliar faces), while being simultaneously eye tracked. Consistent with other work, the ASD group spent significantly less time fixating on the eyes than controls across tasks. Furthermore, for both tasks, the NT group showed significantly greater activation in the bilateral FFA in response to faces compared with the ASD group. Importantly, and as hypothesized, FFA activity was strongly and positively correlated with the amount of fixation to the eye region in the ASD group, suggesting that diminished fixation to the eyes in faces may account for this FFA hypoactivation to faces.

All together, the evidence regarding hypoactivation of the FFA points to the following: Individuals with ASD do not appear to exhibit a pure functional abnormality of the FFA. Rather, the FFA may be hypoactive in some situations due to reduced attention and/or altered gaze. These results, however, still do not provide us with answers regarding the question of what regions are then responsible for abnormal social attention in ASD. For this, we next move on to consider another region known to be important for social attention—the amygdala.

7.4.2 Amygdala

While the FFA is important in facial identity perception, the amygdala has been shown to be critical in early stage processing of facial expressions (Calder, Lawrence and Young, 2001; Morris et al., 1996), among other functions. The amygdala responds quickly to emotionally potent stimuli and its activity varies with valence of the stimuli (Morris et al., 1996; Schultz et al., 2000). Studies have shown that the amygdala is activated by fearful faces (Morris et al., 1996; Hariri, Mattay, Tessitore, Fera and Weinberger, 2003), but this activation appears to be particularly sensitive to the presence of fearfully widened eyes (Morris, DeBonis, & Dolan, 2002), even when processed without conscious awareness (Whalen et al., 2004). A patient with bilateral amygdala damage has also been found to have difficulties in identifying fearful expressions (Adolphs, Tranel, Damasio, & Damasio, 1994). However, this emotion recognition deficit was subsequently found to be due to a lack of spontaneous gaze fixation to the eye region, as explicit instruction to look at the eyes completely restored the patient's ability to identify fearful facial expressions (Adolphs et al., 2005). In NT adults, the magnitude of gaze preference for the eye region of fearful faces is correlated with amygdala activation, suggesting that it may be involved in reflexive gaze orienting toward eyes (Gamer and Büchel, 2009; Adolphs et al., 2005).

The amygdala's responsiveness to eyes and facial expressions makes it a strong candidate region underlying abnormal social attention in ASD (i.e., amygdala hypothesis of ASD; Baron-Cohen et al., 2000), and consequently, its anatomy and functioning in ASD has been highly investigated. However, neuroimaging studies of the amygdala in ASD have reported highly discrepant results, with some reporting hyperactivation to faces (Dalton et al., 2005; Monk et al., 2010; Weng et al., 2011), some reporting hypoactivation (Baron-Cohen, Ring, Wheelwright, Bullmore, Brammer, Simmons, & Williams, 1999; Critchley et al., 2000; Ashwin, Baron-Cohen, Wheelwright, O'Riordan, & Bullmore, 2007; Pelphrey, Morris, & McCarthy, 2007), and others finding initially typical levels of activity but reduced levels with habituation over time (Kleinhans et al., 2009). Anatomically, older adolescents and adults show no differences in amygdala volume (Haznedar et al., 2000), but a longitudinal study of 8–18-year-old boys with and without ASD shows an altered developmental trajectory (Schumann et al., 2004). In this particular study the amygdala was enlarged in 8–12-year-old boys with ASD relative to controls, but this difference was not found in 13–18-year olds due to differing growth trajectories between groups.

Baron-Cohen et al. (1999) were the first group to provide evidence for abnormal amygdala activation in ASD. ASD and NT adults were presented with photographs of eyes and asked to either discriminate gender or indicate the mental state of the person presented. The NT group was more accurate in both tasks and demonstrated significantly greater activation of the left amygdala throughout the tasks, while the ASD group did not. Critchley et al. (2000) also compared ASD and NT individuals on two different facial discrimination tasks—one involving the emotion (explicit emotion processing) and another involving the gender (implicit emotion processing) of faces depicting different emotions. Individuals with ASD exhibited hypoactivation of the left amygdala compared with NT controls during the implicit but not the explicit task. Furthermore, Ashwin et al. (2006) found NT adults to show greater left amygdala and left OFC activation to emotional faces, with only NT individuals displaying varying degrees of amygdala activation with regard to the intensity of fearful expressions. Hypoactivation of the amygdala has also been found in individuals with ASD when viewing dynamic facial expressions (Pelphrey et al., 2007).

However, when gaze was monitored along with fMRI data acquisition, Dalton et al. (2005) again found highly revealing results regarding amygdala activity in ASD. Like FFA activity, amygdala activation in the ASD group was strongly and positively correlated with the amount of time spent fixating the eye region, but this was not the case in the control group. All of these observations, combined with behavioral data indicating abnormal social attention in ASD, highlight the importance of monitoring visual attention in conjunction with brain activation.

Yet even with attention carefully monitored and equated across groups, neural differences of the amgydala have still been found. For example, rather than recording eye movements, one fMRI study implemented an attention-cuing paradigm to provide a measure of a participant's attentional bias (Monk et al., 2010). ASD and NT adults viewed emotional and neutral face pairs, after which a target appeared in the congruent (emotional face) or incongruent (neutral face) location. Participants then pressed a button to indicate the location of the target. The reaction times varied based on which facial expression draws more attention, with bias scores reflecting the difference between reaction times of incongruent and congruent trials. There were no differences between groups in attention bias, but the ASD group showed abnormal brain activity nonetheless, with greater right amygdala activation in response to happy and sad faces compared with controls. A separate experiment by this same group (Weng et al., 2011) attempted to control for possible group differences in attention in a different way; in this case, by presenting face stimuli for only a short amount of time (250 ms) to preclude gaze away from faces. Here, they also found that individuals with ASD exhibited greater amygdala activation compared with controls. Together these findings suggest that hypoactivation of the amygdala in ASD may simply be due to attentional differences between groups, and when attentional differences are considered, individuals with ASD may rather show increased amygdala activation to faces. Despite these discrepancies, these studies collectively provide evidence for abnormal amygdala activity in ASD, though more research is needed.

Comparing individuals with ASD to those with amygdala lesions can provide further insight into whether amygdala dysfunction may underlie the type of social attentional abnormalities seen in ASD. Much of this insight has so far come from studies of a single patient, known as SM, whose rare genetic condition (Urbach-Weithe disease) caused bilateral calcification of her amygdala (Adolphs, 2010). Like in ASD, SM exhibits reduced gaze to the eye region of faces (Adolphs et al., 2005; Spezio, Huang, Castelli, & Adolphs, 2007b), with this effect being particularly pronounced in the first few fixations of a face. A study by one of us (Kennedy and Adolphs, 2010) found that when SM was shown a picture of a face to which she had to saccade, she only initially fixated the eyes on 15 % of the trials, in contrast to controls who first fixated eyes 78 % of the time. However, when this same patient was explicitly instructed to fixate the eye region, she was able to do so, and her previously deficient ability to identify fearful facial expressions became normal (Adolphs et al., 2005). This points toward a role of the amygdala in directing one's gaze to important social information.

Kennedy and Adolphs (2010) further studied the relationship between the amygdala and gaze by having SM and controls explore faces using a gaze-contingent eye tracking paradigm that only revealed a small region of the face in real time at the location being fixated. This task eliminates the competition between facial features and forces the participant to deliberately seek out features to fixate using top-down attentional control, as opposed to bottom-up attentional processes. Remarkably, SM's fixation patterns to the face normalized; the time she spent fixating the eye region was statistically indistinguishable from that of controls. This suggests that during unrestricted viewing, her fixations were perhaps influenced by attentional competition with other aspects of the face. This is consistent with fMRI studies of amygdala functioning in NT adults. Gamer and Büchel (2009) found that the amygdala is activated when individuals fixate the mouth and then subsequently make a saccade toward the eyes, but not the other way around (i.e., when one fixates the eyes, and then saccades toward the mouth). This implies that gaze to the eyes is driven by the amygdala. Taken together, these results suggest that the amygdala is not necessary for processing emotion information from the eyes, but rather required for spontaneous attention to socially or emotionally salient emotion within the face (Adolphs et al., 2005).

Despite some similarities in how people with ASD and amygdala lesions visually explore faces, Birmingham, Cerf, and Adolphs (2011) argue that these two groups may do so for different reasons. While SM appears to look less at eyes due to an exaggerated sensitivity to the bottom-up saliency of the mouth, individuals with ASD may be showing an abnormal top-down bias away from the eyes and toward the mouth (Neumann et al., 2006). To test this theory further, SM, adults with ASD, and NT controls were shown ecologically valid photos of complex social scenes while being presented with three conditions—Neutral (determine what kind of room the scene depicts), Description (describe the scene), and a Social Attention task (describe where the people in the scene are directing their attention). Previous research found NT observers to increase their fixations to the eyes of the people during the Social Attention condition relative to other conditions (Birmingham, Bischof and Kingstone, 2008). As expected, NT controls showed an overall greater proportion of fixations to faces and particularly the eyes, while also looking more at the eyes when the task required greater social attention. SM and the ASD groups were similar in that both looked less at the eyes, but the results showed more differences between these groups than similarities. For example, SM showed significantly more fixations to the mouth especially in the earliest fixations, while the ASD groups did not show this effect. SM also showed intact top-down modulation of gaze by task, increasing her gaze to eyes during the social attention condition. However, the ASD group failed to increase their fixations to eyes for this condition, suggesting an impaired top-down modulation of gaze in response to task demands. The authors argued that the amygdala is critical for stimulus-driven social attention, but not endogenous, top-down control of social attention.

Together, the studies reviewed in this section indicate that the amygdala is a key node implicated in social attentional processes in NT individuals, and whose dysfunction is likely to contribute to certain aspects of the social attentional phenotype in ASD.

7.4.3 Superior Temporal Sulcus (STS)

In addition to abnormal attention to social stimuli, individuals with ASD often exhibit gaze-processing deficits, having particular difficulties with following and utilizing information derived from gaze shifts as described earlier (Freeth, Chapman, Ropar, &Mitchell, 2010; Riby, Hancock, Jones, & Hanley, 2013). Many studies have demonstrated the role of the STS region in processing eye movements of others (Puce et al., 1998; Wicker, Michel, Henaff, & Decety, 1998; Allison, Puce, & McCarthy, 2000). For example, dynamic eye-gaze changes of both direct and averted gaze produce strong activation in the bilateral STS of NT individuals (Wicker, Michel, Henaff, & Decety, 1998). Attention to gaze elicits stronger STS response than attention to identity (Hoffman & Haxby, 2000), and lesions of this region have been shown to impair gaze direction judgments in monkeys (Campbell, Heywood, Cowey, Regard, & Landis, 1990). The STS is also sensitive to the social context in which the gaze shift occurs, with differential activation based on whether the gaze shift is perceived as consistent or inconsistent with the subject's expectations regarding the observed person's intentions (Pelphrey, Singerman, Allison, & McCarthy, 2003). It is thought that the STS is involved in processing social information conveyed by gaze direction (Allison et al., 2000), a skill in which ASD individuals show difficulties (Riby et al., 2013).

Behavioral studies have demonstrated that individuals with ASD are able to perceive gaze direction cues (Swettenham et al., 2003), though perhaps less reliably (Freeth et al., 2010), and yet show impairments in their ability to link the direction of gaze with the observed person's intentions (Riby et al., 2013). These impairments have been attributed to a theory of mind process; namely, that a person with ASD specifically misses the mentalistic significance of the gaze (Baron-Cohen, 1995). If this were true, we could expect brain regions normally involved in eye-gaze processing to be insensitive to the intentions that are conveyed by gaze shifts. Pelphrey, Morris, & McCarthy (2005) tested this hypothesis by presenting ASD and matched NT controls with an animated virtual avatar that shifted their gaze to look either toward a target (congruent condition) or toward an empty location away from a target (incongruent condition). Throughout the fMRI task, participants also pressed a button in response to a gaze shift, which both groups were able to do equally well. Similarly, both groups demonstrated STS activation in response to viewing eye-gaze shifts. However, only the NT group showed differential activity in response to congruent compared with incongruent gaze shifts in this region.

Direction of eye gaze, in addition to indicating intentions, can inform us of potentially harmful situations in our environment (Olsson, Nearing, & Phelps, 2007). Humans are generally more sensitive to direct compared with averted gaze of neutral faces (Senju and Johnson, 2009). However, a person with averted gaze and a fearful facial expression is not only socially and emotionally engaging, but also alerts the observer to potential environmental danger (Hadjikhani et al., 2008). NT individuals detect averted gaze in a fearful face faster (Adams & Kleck, 2003) and rate the expression as more intense than the same expression with direct gaze

(Sander, Grandjean, Kaiser, Wehrle, & Scherer, 2007). A recent study by Zürcher et al. (2013) investigated the neural responses to fearful averted versus direct gaze in young adults with ASD. While the NT group exhibited increased activation in posterior STS, FFA, and anterior insula, the ASD group failed to demonstrate increased activation in response to fearful faces with averted gaze. Furthermore, eye tracking data collected throughout the study showed no differences in the time spent on the eyes between gaze conditions or groups, strongly suggesting fixation differences did not underlie these observed differences between groups. The absence of activation has been suggested to reflect the inability to grasp the increased emotional valence of averted gaze in the fearful face. Taken together, these results thus support the theory that gaze processing deficits in ASD are not based on a general deficit in gaze discrimination, but rather due to a failure to use the social meaning of gaze.

7.4.4 Electrophysiological Measures of Social Attention

In addition to fMRI, electroencephalography (EEG) is a widely used method in the field of social neuroscience to measure neurophysiological responses to social stimuli. While fMRI provides excellent spatial resolution of brain activity, EEG provides superior temporal resolution in comparison. EEG measures electrical potential differences across the scalp that reflect underlying neuronal activity of the brain. Neuronal activity is often measured as event-related potentials (ERPs), i.e., changes in brain activity that are phase locked to the stimulus. Since ERPs reflect a response to a specific stimulus, researchers can use it to quantify the speed at which the stimulus is processed. Furthermore, EEG does not require participants to be lying down, which makes it ideal for testing individuals across age and functioning levels that otherwise may not be suitable for fMRI. On the other hand, EEG has relatively poor spatial localization compared with fMRI, underscoring the importance of utilizing both methodologies to fully understand brain activity.

As discussed extensively by Puce et al. (Chap. 4, this volume), ERP studies involving NT individuals have found robustly different patterns of brain activity in response to faces compared with non-face objects. In particular, the N170 is a right-lateralized, negative ERP peak occurring approximately 170 ms after stimulus presentation over the lateral posterior region of the scalp (Bentin, Allison, Puce, Perez, & McCarthy, 1996). Though it may be evoked by non-face stimuli, faces and even eyes alone evoke shorter N170 latencies and larger amplitudes compared with objects (Bentin & Deoull, 2000). Various manipulations to the face stimuli such as inversion, decomposition, as well as movements in eyes and mouth all influence N170 activity (Eimer, 2000; Itier & Batty, 2009).

Given the fMRI findings of aberrant activity in regions associated with face processing in ASD, it is not surprising that many have observed similarly atypical ERP responses (see Feuerriegel, Churches, Hofmann, & Keage, 2014 for review). For example, McPartland et al. (2004) carried out a study assessing the temporal aspects of the neurophysiological response to faces in individuals with ASD, predicting the ASD group to exhibit impaired temporal processing of faces (i.e., slower neurophysiological response), as indicated by longer N170 latencies in response to faces. Age and IQ matched ASD and NT adolescents and adults viewed upright and inverted pictures of faces and furniture during EEG recording. In addition, participants were assessed for their facial recognition memory. As hypothesized, the ASD group exhibited abnormal temporal processing of faces, with significant differences in N170 latency. More specifically, the ASD group showed significantly longer N170 latencies to faces compared with controls. While the NT group showed significantly longer latencies to inverted rather than upright faces, the ASD group did not, suggesting less sensitivity to the configural alteration of the faces. Furthermore, the ASD group failed to exhibit the standard right lateralization in N170 amplitude to faces, suggesting atypical cortical specialization. Individual differences in the latency of the N170 were correlated with performance on the face recognition task in the ASD group. Slower left hemisphere N170 latency to both upright and inverted faces was associated with better face recognition performance in individuals with ASD, yet faster latencies were associated with improved face recognition in the NT group. Investigators interpreted these findings as evidence of not only atypical cortical specialization, but also different face processing strategies from those of NT individuals.

Differential N170 activity has also been found in response to emotionally salient face stimuli in this population. A recent study by Wagner et al. (2013) examined both the visual scanning patterns and ERPs to emotional faces compared with nonsocial stimuli (houses) to examine how these neural measures of face processing differ across stimuli. ASD and NT adolescents and adults viewed faces conveying angry, fearful, or neutral expressions and houses during simultaneous eye tracking and EEG recording. While the eye tracking measures revealed very similar scanning of faces between groups, ERP measures revealed significant differences. The ASD group in particular showed a lack of neural differentiation between emotion types, while NT participants showed significantly larger N170 amplitudes to fearful faces compared with angry faces. In response to houses, individuals with ASD showed a larger amplitude P1 component (also known as P100, which is a positive ERP component at 100 ms after stimulus onset) compared with controls. Increased P1 responses are thought to indicate enhanced early visual processing and attention (Heinze, Luck, Mangun, & Hillard, 1990), which suggests the ASD group was allocating increased resources for processing nonsocial compared with social stimuli. Lastly, this study revealed significant correlations between visual fixation patterns and neural processing of faces in the NT group, but these relationships were not found in the ASD group. Greater proportion of time spent scanning the eye region was associated with faster N170 responses to faces in NT individuals, which is thought to indicate efficient face processing. In contrast, those who spent a greater proportion of time scanning the mouth showed slower N170 responses. These results were in line with McPartland et al. (2004)—faster N170 latencies associated with better facial recognition in the NT group, but not the ASD group. The lack of association between visual scanning and neural responses further suggests that the ASD group utilized different strategies of face processing.

These results are consistent with many of the fMRI studies indicating abnormal face processing as implied by reduced FFA and abnormal amygdala activity (e.g., Schultz et al., 2000; Pierce et al., 2001; Baron-Cohen et al., 2010; Critchley et al., 2000). However, it is important to keep in mind that when attention is explicitly directed at the eye region with fixation points at the center of the face, individuals with ASD show more normative neural activation (Hadjikhani et al., 2004). Furthermore, simultaneous eye tracking during free viewing of faces suggests that diminished gaze fixation to eyes in particular may account for aberrant activation of areas involved in face processing (Dalton et al., 2005). In light of these findings, Webb et al. (2012) conducted a similar experiment to that of McPartland et al. (2004), but attempted to manipulate visual attention to the stimuli. ERP responses of ASD and NT adults matched on age and IQ were collected while participants viewed images of upright and inverted faces and houses. However, attention was directed to the center of the stimuli by a cross hair that appeared prior to stimulus onset. When attention was cued to the appropriate area around the core features of the face, the two groups demonstrated similar P1 and N170 responses, with greater amplitude and faster latency to faces than houses. Some have proposed that the N170 is mediated by the eye region (Doi, Sawada, & Masataka, 2007; Nemrodov, Anderson, Preston, & Itier, 2014), thus the cued attention to the eyes may have facilitated the normative N170 and P1 response in the ASD group in this study. However, the ASD group failed to exhibit differential ERP responses to upright versus inverted faces unlike the NT group, consistent with McPartland et al. (2004). These results together with the previously discussed fMRI studies that have taken visual attention into consideration provide further evidence for abnormal social attention underlying differential neural activation in ASD.

Yet, despite all of this research, the neural origins of abnormal social attention remain largely unknown, as none of these regions alone are able to provide a sufficient explanation for the social attentional differences observed in ASD. As briefly mentioned in the beginning of this section, recently researchers have argued that abnormal activation in areas like the FFA, amygdala, and STS is not driven by a primary (i.e., causal) neural dysfunction within any of these regions, but rather neural abnormalities in brain circuitry (Schultz, 2005; Dalton et al., 2005). Consequently, there has been a shift in the field toward taking a systems-level approach to understand the functional interactions within and between different brain networks, and further research efforts with this network perspective will be important in elucidating the origins of atypical social attention in ASD.

7.5 Summary

This chapter reviewed the current literature exploring social attentional differences in ASD, resulting social cognitive deficits, and possible neural correlates. The literature is vast and many studies report discrepant findings. However, in general, researchers seem to agree that individuals with ASD show a wide range of differences in social attention as observed in the orienting to (Clark et al., 2008) and visual scanning of faces (Pelphrey et al. 2002; Klin et al., 2002; Speer et al., 2007), scanning of social scenes more generally (Fletcher-Watson et al., 2009; Santos et al., 2012), and responding to eye gaze (Freeth et al., 2010; Riby et al., 2013). The functional consequences we have discussed include deficits in judging facial identity (Blair et al., 2002) and recognizing emotional facial expressions (Wallace et al., 2008; Corden et al., 2008), and there are likely more downstream consequences on social cognition more broadly. And, while some studies have found that some adults with ASD show intact abilities in these domains, it has been suggested that those individuals may be utilizing different strategies. Thus, compensatory mechanisms may be playing a significant role in their success on tests of social processing (Grossman et al., 2000; Spezio et al., 2007a; Baez et al., 2012), as can sometimes be revealed with more sensitive behavioral and neural measures.

We focused on three brain regions (the FFA, the amygdala, and the STS) that may underlie particular aspects of abnormal social attention in ASD. While some studies have found robust differences in neural activation in these regions (Schultz et al., 2000; Baron-Cohen et al., 2010; Dalton et al., 2005; Pelphrey et al., 2005), many have also reported no differences. We suggest that one possible factor underlying these discrepancies is due to differences in experimental tasks used, and whether or not they accounted for possible social attentional differences between groups. For example, while the FFA has been shown to be significantly less active in ASD when viewing faces, its activity is strongly and positively correlated with the amount of fixation to the eye region for individuals with ASD, which suggests that social attentional abnormalities may underlie the FFA hypoactivation to faces in other studies (Hadjikhani et al., 2004; Dalton et al., 2005). Individuals with ASD, while able to identify gaze shifts in others, fail to show modulated STS activity to gaze in conjunction with particular expressions or target locations (Zürcher et al., 2013). These results suggest that gaze processing deficits in ASD are not due to a general deficiency in perceptual discrimination, but rather a failure to derive appropriate social information from the gaze shift observed. Lastly, ERP studies have also showed abnormal N170 responses to faces in ASD (McPartland et al., 2004; Wagner et al., 2013), but additional studies have found more normalized responses when attention is cued to the eyes of the face stimuli (Webb et al., 2012). Such findings further support the idea that aberrant visual social attention strongly impacts neural differences in ASD, in terms of both regional activation and the temporal dynamics of brain activity.

7.6 Outstanding Questions and Issues for the Field

Thus, while these studies have contributed importantly to our understanding of the neural underpinnings of ASD, perhaps their most important contribution has been to highlight the critical role of social attention. With altered social attention comes altered neural responding, and with normative social attention comes more normative neural activity. This suggests that social attention profoundly shapes how individuals not only seek out information from their environment, but also that it has downstream consequences on how they process that information. Like other modulatory systems (arousal, reward, etc.), attention influences nearly every aspect of human cognition.

When considered from a developmental context, the implications of altered social attention become clear—individuals with an ASD may not be extracting the relevant social information from their environment, their brain thus fails to respond in a normal way to social information, and they fail to develop expertise within the social domain. This lack of expertise likely has self-reinforcing properties, such that social information becomes less and less prioritized, and social competencies lag behind their typically developing peers. In order to function in our highly social world, compensatory processes are likely developed, but these processes seem to lack the fluidity, spontaneity, and ease that characterize social processes for typically developing individuals.

Some have argued that social attentional differences are the downstream effects of social motivational deficits which, when combined together, lead to social cognitive deficits (Chevallier et al., 2012). Yet, additional experimental paradigms to sensitively quantify social motivation are needed. While questionnaires such as the Social Responsiveness Scale (SRS; Constantino, & Gruber, 2002) provide subscales of social motivation, these questionnaires require either the individual's or their caregiver's insight. There is thus a need for the development of experimental manipulations that can directly measure social motivation, and examine how motivational factors relate to the abnormal allocation of attention and subsequent social functioning. The ability to sensitively quantify social motivation may impact the development of individualized treatments for ASD. For example, if a particular individual has low social motivation and correspondingly altered social attention, interventions aimed to increase social motivation (e.g., Floortime (Greenspan & Wieder, 1997)) may result in more normative patterns of social attention, and may be more impactful than other types of interventions (e.g., social skills training) for that particular individual. The apparent normalization of brain activity when social attention is taken into account bodes well for the development of interventions for children and adults. These findings suggest that individuals with ASD may not engage their brains in the typical ways, but also suggest that they may be capable of doing so, given particular instructions, conditions, and/or motivation.

Beyond behavioral interventions, the neuropeptide oxytocin has been pointed to as a possible point of therapeutic intervention of social attention and motivation, as it is hypothesized that aberrant oxytocin systems contribute to social deficits in ASD (Waterhouse, Fein, & Modahl, 1996). In mammals, oxytocin has been associated with the development of prosocial behavior, such as maternal attachment, and abnormal oxytocin levels have been reported in children with ASD (Modahl et al., 1998). Furthermore, oxytocin concentrations are positively predictive of theory of mind and social communication performance in both ASD and non-ASD cohorts, highlighting its role in social functioning in humans (Parker et al., 2014). While more studies need to be conducted to verify its role in social attention, intranasal oxytocin administration has been shown to increase fixation time on core areas of faces (particularly the eyes) and promote social approach behaviors (Andari et al., 2010), improve emotion recognition (Guastella et al., 2010) and affective speech comprehension (Hollander et al., 2007) in individuals with ASD. It is, however, implausible that there will be a single treatment that will work for all individuals with ASD, given its heterogeneous biological underpinnings.

This heterogeneity, in terms of both etiology and behavioral expression, also likely underlies some of the discrepant findings across studies and laboratories. Heterogeneity is perhaps the least disputed feature of the condition (Geschwind & Levitt, 2007), and not only impacts replication across study samples, but also suggests that methods and analyses need be sensitive to individual differences. Rather than increasing sample sizes in an attempt to identify a statistically significant group difference between ASD and NT individuals, perhaps researchers should begin focusing on individual, idiosyncratic patterns of abnormal social attention and neural activity, and begin to ask how these individual patterns relate to particular deficits or strengths in social functioning within that individual (e.g., Byrge, Dubois, Tyszka, Adolphs, & Kennedy, 2015). In other words, researchers may be better served by embracing the heterogeneity characteristic of ASD, rather than fighting against it.

So, where do we go from here? While we have come a long way in our understanding of ASD, many questions still remain in understanding the etiology and structure of atypical social attention in ASD:

- Although social attention and social cognition seem to be associated, the causal relationship between the two is unknown. Does abnormal attention produce abnormal cognition, or does abnormal cognition result in altered attention? In other words, is altered gaze a cause or side effect of altered cognition? The development of new experimental approaches to address these questions will be required (Bush, Pantelis, Morin, Duchesne, Kagemann, & Kennedy, in press).
- Does normalizing social attention normalize social perception and social responding, like it seems to do for brain activity? For example, if individuals with ASD are instructed to look at the eyes in faces, are they able to use this information effectively to make correct social judgments?
- What aspects of altered eye movements in ASD can be attributed to bottom-up attentional differences, top-down attentional differences, or a combination of the two?

- Can eye tracking measures of social attention be used for diagnostic purposes? While findings from infants point toward this possibility (Jones & Klin, 2013), it is less clear whether this approach will be effective in older children and adults.
- To what degree is abnormal attention in ASD domain-specific? Can we dissociate basic attentional processes from abnormal social attentional processes in ASD?

7.7 Conclusions

Studies using stimuli and experimental paradigms with greater ecological validity, along with a focus on individual differences, will be crucial for a complete understanding of social attention in ASD. Furthermore, going beyond region- and location-centric studies of potential neural mechanisms, and toward a systems-level approach to link behavior to network-level functioning, will be critical in illuminating the origins of atypical social attention in ASD.

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Chapter 8
A Look Toward the Future of Social Attention Research

Bennett I. Bertenthal and Aina Puce

8.1 Next Steps

A good deal of our brains and our everyday activities are devoted to interacting with people, and so it stands to reason that we should be keenly interested in how these interactions occur. The chapters in this volume represent a small sample of a broad multidisciplinary effort to understand how humans navigate their labyrinthine social world. Social attention has occupied a central role in this endeavor because the social information available to the perceiver will depend first and foremost on what we select to encode either consciously or unconsciously. In this final chapter we begin by summarizing some of the major findings from each chapter in this volume and then discuss why these findings are still tentative and incomplete. We conclude with some recommendations on how social attention should be investigated in the future. We argue that social attention should be broadened and studied as a dynamical system—a system that is high-dimensional, multilevel, multicausal, and nonlinear.

Before beginning our summary, we digress to point out that until recently laboratory studies of social attention have followed the standard practice of presenting stimuli that were simple and easy to control. For example, isolated static photos of faces or schematic faces consisting of a few features in a circle were often used to study gaze cueing and its neural correlates. Likewise, biological motion was reduced to point-light displays, but these impoverished stimuli obviated the opportunity to learn what might occur in the presence of more complex information, such as we would encounter in daily life. Each of the preceding chapters represents a "sea change" in the study of social attention in that new research was reviewed that

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included more complexity than has heretofore been typically studied with a view to understanding how our social attention systems are taxed in everyday life. This complexity takes on a number of forms, from dynamic stimuli depicting human facial motion to complex visual scenes from the real world. As a consequence of these new research directions, a number of unanswered questions have emerged that merit serious and concerted future research efforts. The future is bright for the field of social attention: There are many new exciting research directions to pursue using more complex stimuli and data collection/analysis methods. It is also important to note that these new research directions could not have been undertaken without the careful, laboratory-based investigations that have been devoted to investigating social attention over the past 50 years.

Each chapter in this volume represented a different perspective on social attention ranging from developmental to cognitive to social neuroscience to clinical. Our goal was to show that these different perspectives are necessary and complementary for understanding how social attention forms a basis for many of our social behaviors. Given the diversity of views covered in this volume, we note that there was considerable variation with regard to what sorts of social information was reviewed. Moreover, we feel obliged to point out that there did not appear to be any standard definition of social attention in the literature. In our introductory chapter we attempted to define social attention in a broader sense, so as to encompass the many facets of this multidisciplinary area of research. Some chapters in this volume focused primarily on faces and eye gaze, whereas others focused more broadly on the actions represented, and interpretations made, of both the stimuli, as well as subjects' responses. In fact, the direction taken in some of the chapters suggested that social attention can be considered mainly from the standpoint of the stimulus information processed by the observer (e.g., eye gaze of the stimulus). In contrast, other chapters viewed social attention primarily from the standpoint of selection and orienting by the observer, and were thus more concerned with how the observer attends to the social information. This variation in focus might, in part, arise from the different disciplines in which these studies of social attention were based. Most chapters in this volume reviewed research germane to both approaches, but it is helpful to keep in mind that while the goals of these two research questions are complementary, their emphases are somewhat different.

8.2 Summary of Chapters

We began the volume (Puce and Bertenthal, Chap. 1, this volume) by examining how social attention research has evolved over the past 50 years since the term "social attention" was first coined, considering also other developments in science and technology. We also provided definitions for the most commonly used terms in social attention research, and examined a number of emerging themes in the field.

Bertenthal and Boyer (Chap. 2, this volume) noted that social attention is a dynamic process that begins at birth, but continues to develop in association with many other skills, including perceptual development, action understanding, and the coordination of joint actions. By emphasizing social attention as a process and not just a product of development, they were proposing a new research agenda. No longer it is sufficient to study how infants look at faces and eye gaze, because the key questions now revolve around the *dynamic* distribution of attention to social stimuli and how attention changes with experience, task, and context. Although much can be learned from well-controlled and rigorous laboratory experiments, it is too often the case that these types of experiments strip away what is most essential to the study of attention, i.e., the process of attentional selection and contextual modulation. For example, evidence was presented that 8- and 12-month-old infants attend to faces differently in semi-naturalistic social interactions depending on the gaze direction and object-directed actions of the social partner. Furthermore, infants' distribution of attention to social and nonsocial information will depend a great deal on age and experience. As infants continue to develop during their first year, attentional orienting becomes more controlled by endogenous (goal-directed) processes, and as such, offers a window into the cognitive and social development of the child.

Currently, the majority of research in early cognitive and social development focuses on the specific skills that develop at different ages. The unfulfilled promise of studying attention is that we can learn more about how infants acquire these skills with age, for example: Do infants direct their attention to the most relevant locations in a scene? Do they share attention with a social partner? By operationalizing attention in terms of eye movements, researchers are able to obtain a direct read-out of where and what infants are looking at and how this changes over real and developmental time. One important implication of focusing more on social attention as a process is that it becomes apparent that it is *interconnected with other processes* and does not simply function as the first stage in a unidirectional sequence of social information processing. Instead, social attention is reciprocally related to social understanding, and thus any experience that contributes to the development of social attention will, in turn, contribute to social understanding and vice versa. It is for this reason that Bertenthal and Boyer claim that action understanding will develop not only as a function of motor experience (e.g., Woodward & Gerson, 2014), but also as a function of more focused attention on the relevant actions themselves.

Reid and Dunn (Chap. 3, this volume) also focused on infants and continued the theme of studying social attention as a process; in this case, the emphasis was on neural processes. Different components of ensemble event-related potentials (ERPs) computed from noninvasive electrophysiological measurements of brain activity reveal early evidence of face and eye gaze processing (N170), memory processing and attentional orienting (mid-latency negative component, Nc), as well as context updating (positive slow wave, PSW). A very interesting finding associated with this latter component is that 4-month-old infants show an increased PSW to direct as opposed to averted gaze, but only for angry faces. This finding is reminiscent of the results reported by Bertenthal and Boyer (Chap. 2, this volume) demonstrating that infants' attention to faces is contextually modulated. Importantly, the evidence presented in this chapter suggests that context updating occurs not only for gaze cues, but also for the processing of objects that are the *targets* of these cues. These findings reveal that infants begin to learn about objects from bouts of joint attention much earlier than is typically reported, and moreover underscore that social attention interacts with other processes, such as object perception, to facilitate the cognitive and social development of the child.

Given the limited repertoire of behaviors available to young infants, it is certainly advantageous to measure infants' processing of information without the need for a behavioral response. In spite of the benefits of this measure, its use for studying the development of social attention has been limited in part because of the technical complexities associated with studying brain activity and also because of high attrition rates. Reid and Dunn discussed a number of procedures for minimizing drop-out rates, including the use of live and dynamic stimuli, which are preferable when studying social attention. In addition, Reid and Dunn advocated using electroencephalography (EEG) analyses that examine oscillatory activity because there are new techniques emerging to analyze these data based on less data than required to analyze ERPs.

Reid and Dunn also briefly discussed the promise of these early measures of social attention for predicting later development, and especially the development of social disorders, such as autism. While thus far the results have not been that promising, there is reason for optimism given the advent of new techniques using discriminant function and machine-learning methods that can improve the reliability and predictive validity of these measures. Lastly, Reid and Dunn suggested that the predictive validity of early measures of social attention benefits from longitudinal testing and repeated measures, a claim that is directly supported by Schultz, Jones, and Klin (Chap. 6, this volume).

Similar to the preceding chapter, Puce, Latinus, Rossi, daSilva, Parada, Love, Ashourvan, and Jayaraman (Chap. 4, this volume) focused on the neural correlates of social attention, but in this case it was in adults. Most of the review was concerned with one particular behavior associated with social attention, i.e., changes in gaze direction. Eye gaze communicates a good deal of information about the intentions and motives of the subject and simply perceiving the eyes shift toward or away from the observer will change one's interpretation of the current situation. As the authors discuss, the "social brain" consists of at least four brain networks or subsystems that have been identified mainly with functional magnetic resonance imaging (fMRI) studies. Two of these are especially relevant to how gaze behavior is processed (a mentalizing network and an amygdala network). The behavior of the brain regions comprising these two networks has been extensively studied with fMRI, and is reviewed briefly. In addition, by studying the neurophysiology (with either EEG or magnetoencephalography [MEG]) elicited by changes in gaze direction that are presented in specific contexts, we are able to glean important insights into the time course of processing this information.

The N170 is an ERP that has been linked to face processing, and that is also sensitive to changes in eye position. Intriguingly, a robust N170 is elicited to the gaze stimulus regardless of whether the eyes are stationary (in the onset of a static face or isolated eye stimulus) or shifting (in a persistent dynamic face), and whether the head is oriented in the same or a different direction from the eyes. Important processing differences are revealed, however, by measuring N170 amplitudes and latencies in response to different gaze behaviors, including opening and closing of the eyes, and in different social contexts. Some of these processing differences are attributable in part to low-level changes, such as the changing local luminance/contrast between the iris and sclera of the eyes when they move. It is therefore critical to distinguish ERP modulation that is produced by changes in low-level features from that which reflects the processed meaning of the social information. Puce and colleagues provide a comprehensive overview of both what is now known about the N170 as a neural correlate of gaze behavior as well as identify open questions for continuing research in the field.

This review is somewhat paradoxical in that its content is narrower than any of the other chapters, yet the issues addressed are some of the most complex and difficult to disentangle. An important contribution by Puce and colleagues is to propose a new model potentially capable of resolving some of the seeming contradictions in the literature. This model is based on two modes of social information processing: a “Default” mode and a “Socially Aware” mode. In the Default mode, the social meaning of the stimulus is irrelevant to the task and elicited neural responses: stimulus information is processed primarily at a sensory level in terms of low-level features (e.g., spatial frequency, luminance/contrast, and basic facial features). During this mode of processing N170 amplitude and latency is modulated by the strength of the incoming sensory information. This modulation of N170 activity can provide some information regarding the stimulus, should a sudden shift to Socially Aware mode be required. In the Socially Aware mode, where the meaning of the gaze behavior is consciously evaluated, sensory gain increases so that there are no differences in N170 across different social attention conditions. This increased sensory gain allows for the modulation of later ERP activity beyond 350 ms by stimulus condition, which maximizes the interpretation of the incoming stimulus relative to the existing social context. Although this model is still preliminary, it offers some key insights into how the time course of neural processing maps onto the goals and intentions of the observer.

Nasiopoulos, Risko, and Kingstone (Chap. 6, this volume) began by questioning the sufficiency of traditional laboratory research to study social attention. They provided compelling evidence for disputing the generalizability of findings derived from well-controlled, yet simplified, experimental paradigms, because the social world is filled with situational complexities that influence social attention behavior. Moreover, the simple act of looking at someone else’s eyes is not sufficient to explain why this occurs, especially when looking at another real person, because looking serves a dual function. On the one hand, it is designed to acquire information from the individual who is viewed by the participant, while, on the other hand, it is signaling information about the motives and intentions of the looker. Based on decades of research in social psychology on the effects of *social presence* on one’s behavior, Nasiopoulos and colleagues discuss the implications of this research for studying social attention.

As also discussed in previous chapters, this research demonstrates that social attention is contextually modulated, but now the focus turns specifically to *implied* social presence. A simple reminder or cue, such as a camera, that the subject is being observed can be sufficient to influence how they will respond. These responses reflect a conformance to normative social behavior. This is thought to be the reason why participants modulate their looking behavior depending on their distance from the viewer (e.g., avoiding the gaze of an approaching stranger), or whether the target is live or merely a two-dimensional photo or video recording. Intriguingly, wearing an eye tracker can induce the same effects of social presence because participants believe that their eyes are being monitored. Some of these effects may be short-lived, i.e., exhibit habituation, but nevertheless the results are robust and thus present a caution to researchers studying social attention in the laboratory or in more natural situations. In particular, social responses are determined not only by what the researcher intends to study but also by what the participant is thinking about the situation, or the experimenter's intentions.

This chapter highlights the importance of considering how other people or simply their implied presence influences social attention. As Nasiopoulos and colleagues point out, the findings that implied social presence is often sufficient to influence one's behavior in the same way that real social presence does represents both an opportunity and a challenge for research. In contrast to manipulating the effects of social presence with real people and sacrificing experimental control, it is possible to manipulate and control implied social presence without compromising the social authenticity of the testing situation.

The chapter by Schultz, Jones, and Klin (Chap. 6, this volume) is the last of the three that focused on infants and early development. They emphasized how seeking social information is an adaptive response by typically developing infants, and how departures from this response will result in atypical development because of the cascading effects associated with less social interaction. This seeking of social information is present from birth, and is important not only for its survival value, but also because it enables social interactions and social learning. As such, social attention is conceptualized as a means of preparing infants to benefit from their social environment through an interactive process with the environment that leads to social information becoming more finely attuned with experience. The *canalizing role of early experience* explains why successful adaptation to the social environment leads to new and more advanced social behaviors, but these same processes also explain why less motivation to seek social information leads to atypical social experiences. This is in essence an epigenetic view of development that offers a valuable framework for evaluating the contributions of social attention not only during infancy but also later on in life as well.

One of the major strengths of this developmental view is that it underscores the need for longitudinal research in order to identify the root causes for social cognition disorders, such as autism. The authors devoted considerable attention to a longitudinal study that focuses on early departures from attention to eye gaze. By focusing on the developmental trajectories of both typical infants and those at risk for autism spectrum disorders (ASD), they were able to identify deviant patterns of behavior in children who were subsequently diagnosed with ASD. These results are not meant to suggest that less attention to others' eyes is a cause of ASD, but it represents a marker of emergent social disabilities as well as a mediator of subsequent social and cognitive development. This is a theme that runs throughout the volume and emphasizes that social attention is integral to how we process social information, and that social attention does not function alone. Rather, it is a part of a dynamic and complex process that emerges in both real and developmental time.

Bush and Kennedy's (Chap. 7, this volume) review of social attention deficits in individuals with ASD is a natural complement to the preceding chapter because the focus is on the consequences of aberrant social experiences rather than the early experiences themselves. They discuss both behavioral and neural evidence suggesting that individuals with ASD show differences in their visual scanning of relevant social information in a visual scene, as well as differences in the neural activation of three brain regions (fusiform face area [FFA], amygdala, superior temporal sulcus [STS]) that are involved in processing facial identity, facial expressions, and gaze direction. It is clear from this review that the evidence for social attention deficits is often inconsistent—which is to be expected given the heterogeneity of the ASD participant samples, in terms of both etiology and also behavioral expression. More importantly, these discrepancies reflect the multifarious ways in which social attention can be measured and how the same response can reflect different processing strategies. For example, ERP studies show abnormal N170 responses to faces by individuals with ASD (McPartland, Dawson, Webb, Panagiotides, & Carver, 2004; Wagner, Hirsch, Vogel-Farley, Redcay, & Nelson, 2013), but these responses become more typical when attention is explicitly directed toward the eyes of the face stimuli (Webb et al., 2012). In this latter case, the results do not necessarily imply the same mechanism as found in neurotypical adults, but rather a compensatory mechanism that is guided by some bottom-up process. Likewise, individuals with ASD were able to identify emotional expressions as quickly and as accurately as neurotypical adults, but in a more complex Stroop-type task that included matching and mismatching emotion labels the ASD group's accuracy declined relative to the neurotypical adults (Grossman, Klin, Carter, & Volkmar, 2000).

It is instructive to note that the likelihood of finding differences between ASD and neurotypical adults seems to be related to the complexity and often the subtlety of the presented stimulus information. The failure to detect a fleeting emotional expression or a quick glance in a naturalistic situation may be sufficient to explain why ASD individuals can misinterpret the intentions and motives of others. Although this hypothesis awaits more rigorous empirical testing, it aligns with the suggestions from other chapters that laboratory assessments of social attention can sometimes obscure or even eliminate the critical information necessary for eliciting an appropriate response to incoming social information. The findings reported by Bush and Kennedy offer a number of pertinent suggestions as to which sorts of real-world social interactions are most likely to reveal a misunderstanding of social information due to a deficit in social attention.

8.3 Opportunities and Challenges

8.3.1 New Technologies

Collectively, the chapters in this volume offer testament to the view that social attention is a complex and dynamic process that is interconnected with both higher and lower levels of processing social information. Sensory processing, social cognition, and social categorization are all processes that are interdependent on social attention. Just as visual attention, more generally, is influenced by higher-level processes involving goals and motivation, the same is evident for social attention, and thus it is overly simplistic and misleading to consider social attention in isolation. Yet, this conclusion introduces a serious challenge for both neural and behavioral research that capitalizes on the type of technologically advanced methods (e.g., eye tracking, fMRI, EEG/ERP/MEG) that are becoming increasingly common in the field. These methods have physically constrained the participant as well as the presentation of stimulus information, resulting in rather impoverished activation tasks. Most notably, participants have been typically precluded from moving, and yet this is exactly what they would be doing during a normative social interaction.

In spite of these apparent challenges, there is much room for optimism given the rapid advances in the development of these technologies and in data analysis methods. The advent of wireless technologies is freeing many recording systems from the "umbilical cords" that currently constrain movements. Some laboratories are beginning to experiment with recording EEG while participants are moving (Gramann et al., 2011; Sipp, Gwin, Makeig, & Ferris, 2013), and other laboratories are beginning to conduct hyperscanning experiments with recording of EEG from two participants simultaneously (Lachat, Hugueville, Lemarechal, Conty, & George, 2012). These new approaches require specialized data preprocessing methods that can identify and remove artifacts that are generated by participant movement (Gwin, Gramman, Makeig, & Ferris, 2010). In addition, there is the push to make real-time analysis of these data possible (Mullen et al., 2013). This type of approach has necessitated new developments in EEG amplifiers, which has also been stimulated by developments in video gaming and personal monitoring technology, the latter of which has typically focused on measuring steps, general activity, heart rate, and distance traveled. New options to measure and monitor continuous EEG exist, with smartphone and computer software interfaces to log, analyze, and display data that have been developed. For example, a relatively new low-cost Bluetooth device for crowd-sourced brain research is available from EMOTIV (Everleigh, Australia) and includes 14 electrodes and 9-axis motion sensors for monitoring head movement, and associated gaming software as well as the potential to record EEG data for research. A more basic EEG Biosensor System uses dry electrodes to record a single channel of EEG at a sampling rate of greater than 500 Hz (Neurosky, San Jose, CA) with data viewing applications available for the most common types of smartphones, tablets, and computers.

Naturally, there is much spadework to be done before these new methods are capable of providing reliable data for the interested researcher, but we now live in an age where most technological limitations are short-lived, especially if they are coupled with some commercial application. We suspect that EEG methodology will further benefit from the continuing advances in the video gaming industry that is beginning to introduce wireless brain recording systems with their computer games (SmartBrain PlayStation 3 System & Microsoft Xbox 360 Combo that work with thousands of Sony PlayStation 3 & Microsoft Xbox 360 video games).

Similarly, head-mounted eye-tracking systems are becoming very lightweight and much easier to use with ambulatory participants (e.g., Franchak & Adolph, 2010; Land & Tatler, 2009). Importantly, the latest systems feature two cameras—one that monitors the gaze position of the participant, and a second that monitors what the participant is looking at. This technology is also likely to benefit from other related technologies, such as future incarnations of computer–user interfaces such as Google-glass, or whatever the next generation of wearable technology produces. In spite of the excitement and optimism offered by the new emerging technologies, we must remain sobered by the cautions raised in the Nasiopoulos and colleagues' chapter (Chap. 5, this volume). With each new technological development, the *technology itself can become part of the experiment* and will inevitably influence the perceptions and responses of the participants.

8.3.2 Multimodal Data Collection

As the technological advances that we outlined above become more commonplace, researchers will have increasing opportunities to integrate multiple measures into their studies. The challenge is to develop methods that not only reliably measure all the stimuli and behaviors, but also ensure that they are synchronously recorded. For example, studying individuals who are freely moving about with head-mounted eye trackers supplies continuous information about where the person is looking as well as detailed information about the visual scene. It is critical that this information is synchronized if it is going to be used together to measure coordinated behaviors between individuals. In the future, it will become possible to add continuous EEG information as well as motion analysis information about the movements of the individuals, which will add to the complexity of synchronizing all the data streams. Nevertheless, it is our impression that the real challenge presented by these new technologies will not be the reliable and synchronous collection of data, but rather developing effective strategies to optimize the analysis of multiple time series of data simultaneously.

One of the keys to developing these strategies is the development of new analysis and visualization tools that enable researchers to characterize stimuli and multiple responses as they change over time. An example of such a visualization software tool is one developed by Yu, Zhong, Smith, Park, and Huang (2009) for displaying the eye-tracking behavior of freely moving infants while their motor behaviors and the visible stimuli in the visual scene are also synchronized and

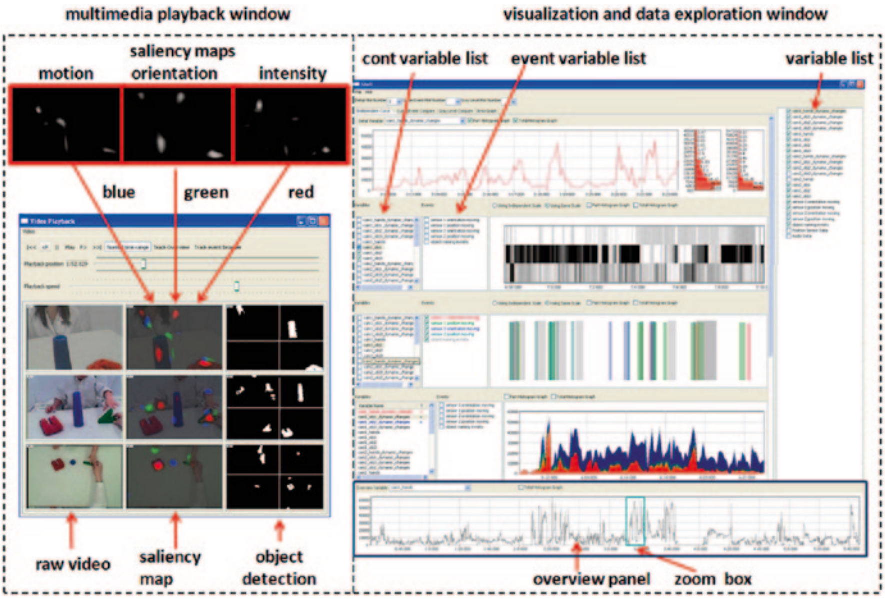

Fig. 8.1 Visualization software of data collected with a head-mounted camera. Saliency maps of image data *(left panels)*, and machine- and observer-coded data during infants' interactions with parent and objects *(right panels)* are shown. These windows are examples of an existing modular system that can be easily modified and extended to suit the goals of the project. (Reprinted with permission from Yu et al., 2009)

shown simultaneously (see Fig. 8.1). The amount of information provided by eye-tracking and video recordings is enormous and can easily become overwhelming. By enabling researchers to visualize multiple data streams at the same time, this tool provides a means for data mining, which is especially useful when theories and principles from the literature have not yet been well formulated. For example, data mining might begin with first observing covariations between different measures (e.g., gaze cueing, head movements, pointing, vocalizations, object-directed actions, and social referencing), and then testing the frequency of these dependencies. If the experimenter was specifically interested in participants' eye movements or neural or autonomic responses to facial expressions, then this behavior could be selected and stored every time it appeared in the video, and the corresponding eye movement or EEG or pupil dilation activity could be displayed and stored as well so that it was available for further analysis. If there is a systematic relation between facial expression and one or more of these variables, it is likely to be first noticed during the dynamic display of the multiple data streams. By using this visualization tool, the experimenter can apply a combination of experience, intuition, and domain knowledge to the problem to decide how to perform quantitative analyses in a modular and flexible fashion (Yu et al., 2009).

A multimodal data analysis system called Mobile Brain and Body Imaging (MoBILAB) has been developed for integrating ambulatory EEG data with motion capture, surrounding audio, video, and other physiological data (Gramann, Jung, Ferris, Lin, & Makeig, 2014; Makeig, Gramann, Jung, Sejnowski, & Poizner, 2009; Ojeda, Bigdely-Shamlo, & Makeig, 2014). Systems such as this will allow the observed behavior and associated EEG phenomena to be assessed in a holistic context that is typical of a real-world environment, and will be ideal for studying processes such as social attention.

8.3.3 Live versus Prerecorded Stimuli

A persistent theme throughout this volume has been that social attention is driven by both bottom-up and top-down processes. It is generally assumed that the bottom-up processes are automatic and reflexive and are influenced by the featural, semantic, social, and affective salience of the stimuli (Gottlieb & Balan, 2010; Todd, Cunningham, Anderson, & Thompson, 2012). In contrast, top-down processes are directed by the goals of the current behavior and are influenced by the participant's evaluation of the social demands associated with the task at hand (e.g., Laidlaw, Foulsham, Kuhn, & Kingstone, 2011). It is worth noting that an individual's goals change from moment to moment, and thus the scan patterns that they display while viewing a specific scene or conversing with someone else will depend on the agenda currently being pursued by the individual. Indeed, this finding was a key contribution of Yarbus' (1967) pioneering work on eye movements in which he reported that individuals would show different scanpaths to the same picture depending on the instructions they were given before looking. Regrettably, the implications of these findings have often been neglected in more contemporary research. One of the current challenges in assessing brain–behavior relationships underlying social attention is how bottom-up and top-down processes dynamically *interact* and contribute to both the perception and production of contextually and socially appropriate behavior. This is a challenge that is not unique to the field of social attention; systems neuroscience and cognitive/social neuroscience, among other fields, are also grappling with this same challenge.

The review by Nasiopoulos and colleagues (Chap. 5, this volume) on the effects of social presence on gaze is a refreshing exception to this current state of affairs. Early in their chapter they review evidence suggesting that task and context will affect gaze behavior, and, in particular, point out that looking at the face and eyes of a live person is much less common than looking at these features in a picture or a video recording. Although there is no reason to dispute this finding, we wish to emphasize that it is certainly not the complete story. During live conversations individuals will look at the other 75 % of the time while listening and 40 % of the time while talking; mutual gaze occupies 30 % of the time (Argyle, 1988). Likewise, parents and infants will devote considerable attention to each other during social interactions (Bakeman & Adamson, 1984).

There are two reasons for raising this issue. The first is to simply make explicit that social attention in the company of strangers is likely to be not comparable to social attention occurring between acquaintances or intimates. Curiously, this point was not discussed in any of the previous chapters. The second reason is that there is the potential to learn a good deal more about the neural processing of social attention in live situations, but only if people devote their attention to each other in these situations. Reid and Dunn (Chap. 3, this volume), Puce and colleagues (Chap. 4, this volume), and Bush and Kennedy (Chap. 7, this volume) all comment on how the measurement of brain activity is more robust and sensitive when social stimuli are presented live as opposed to presented on a computer as two-dimensional pictures or recorded events. Presumably, these stimuli are more arousing and salient, but also the task demands change in the live interaction. A participant will respond to the social attention cues of their partner, who will in turn respond to the behaviors of the participant, and so on. These dynamic interactions between two or more individuals are significantly more stimulating and complex than what can be realistically generated in a static or recorded stimulus display in a laboratory setting. Obviously, there is much more to analyze in these interactions because the current gaze response will be influenced by both previous responses as well as the anticipation of future responses.

8.3.4 First- versus Third-Person Perspectives

It is also useful to keep in mind that social attention can be studied in observers from both a first-person and a third-person perspective. The majority of research discussed in this volume focuses on social attention from a first-person perspective, but the interpretation of social information from the standpoint of viewing an ongoing social scene in the real world or in a movie or video is becoming increasingly informative (e.g., Hasson, Malach, & Heeger, 2010; Torralba, Oliva, Castelhano, & Henderson, 2006; Zacks, Speer, & Reynolds, 2009). When participants view a social scene from a third-person perspective, especially if it has been prerecorded as a movie or video, the number of people on the screen will vary from one to many. This varied visual stimulus has consequences for brain activity: neural activity is monotonically increased with the number of viewed faces (Puce et al., 2013). In the case of viewing a movie, there seems to be fairly good uniformity with regard to whom or what will be attended to by the participant observing this scene because the camera angle and behaviors of the actors will direct attention toward a specific location (Smith, Levin, & Cutting, 2012). One significant limitation of this approach is that the participant is merely a passive observer and does not need to be concerned with how he or she is perceived by the actors. Borrowing from Nasiopoulos and colleagues (Chap. 5, this volume), we could say that there is no social presence to affect the responses of the participant viewing the movie. This situation changes dramatically if the group of observed people is live rather than recorded. Now the participant is not merely a passive observer, even if he or she is relegated to merely watching the behavior of the others. In all likelihood, the presence of the others will trigger some sense of the observer being watched and evaluated which will constrain his or her behaviors. Some research relevant to this issue (e.g., Gallup et al., 2012) was briefly reviewed by Nasiopoulos and colleagues.

What about the study of social attention from a first-person perspective in groups of people? Imagine, for example, a multiparty discussion during a planning meeting with four individuals seated around a table. Do we expect that everyone will focus on whoever is talking, or will attention be more distributed among the different participants? Will participants always look and gesture toward the same individual, or might looking and gesturing function somewhat independently? What role does social status or dominance play as to which individual will be gazed at the most in the four person interaction? These are but a few of the questions that emerge when we scale up the social situation from a two-party dyadic conversation to a group discussion. The study of groups has been a major focus in social psychology for decades (e.g., Lewin, 1947; Zajonc, 1965). Yet, there is little known about how individuals within these groups distribute their social attention during communicative exchanges where the eyes serve as *both a signal and a channel for accumulating information*. We suspect that the role of social attention in group activities represents one of the new frontiers in this field that will require a host of novel methods and models for understanding the complex interactions that will be observed.

8.4 Is Social Attention Specialized?

At an intuitive level, most of us are likely to agree that social and nonsocial attention is different because the information selected serves different communicative functions. Social signals, such as eye gaze or facial expression, are intrinsically alerting because they communicate interest or warnings by conspecifics (Tomasello, 2008). This information appears to take priority over other information and is responded to rapidly and often automatically (e.g., Birmingham & Kingstone, 2009). In contrast, nonsocial symbolic information affects attention because of extensive experience with the symbol and its associated response. For example, an arrow will cue a person in a specific direction because of an overlearned association between its meaning and the correct response. These differences, however, may or may not imply any form of specialization. Both social and nonsocial information could be processed by the same mechanisms, and the only difference therefore might be a function of the stimulus information itself. In actuality, this hypothesis is but one of a number of possible responses to the question of specialization.

A similar diversity of claims about specialization have arisen with regard to language and face perception (e.g., Bruyer & Velge, 1981; Farah, 2000; Hauser, Chomsky, & Fitch, 2002; Kanwisher, McDermott, & Chun, 1997; Pinker & Jackendoff, 2005; Puce, Allison, & McCarthy, 1999; Saffran & Thiessen, 2007; Tovee, 1998), but it has been very difficult to achieve consensus on this issue. One reason for this problem is that there are significant differences in definition and interpretation of what constitutes "specialness" (Liu & Chaudhuri, 2003). At least part of the lack of agreement stems from not distinguishing between three logically separable issues: innateness versus acquisition of expertise, the existence of domain specificity, and brain localization (Bates, 1994). For example, face processing may be domain-specific but not innate, or it may be innate but not localizable within a discrete anatomical brain region. Although a comprehensive discussion of the specialness of social attention is beyond the scope of this chapter, we offer a brief synopsis of some of the issues discussed in the preceding chapters that are germane to this issue.

8.4.1 Innate versus Learned

As reviewed in multiple chapters, neonates are preferentially sensitive to face-like stimuli and they track moving faces longer than other moving patterns of comparable complexity, contrast, and spatial frequency (Easterbrook, Kisilevsky, Hains, & Muir, 1999; Johnson, Dziurawiec, Ellis, & Morton, 1991; Valenza, Simion, Cassia, & Umilta, 1996). Newborn babies less than 3-days-old prefer attractive faces based on internal features and their sensitivity is restricted to the upright orientation (Slater et al., 2000). Young infants are especially sensitive to the presence of eyes in a face (Batki, Baron-Cohen, Wheelright, Connellan, & Ahluwalia, 2001), and distinguish faces whose gaze is directed toward as opposed to away from them (Farroni, Csibra, Simion, & Johnson, 2002). These behaviors ensure that newborns attend to face-like patterns, but this by no means implies that face processing is innate and does not require a good deal of learning.

Shultz, Jones, and Klin (Chap. 6, this volume) present a compelling case for how the development of normative social interactions evolves from the spontaneous seeking-of and acting-upon social information which neonates are preferentially biased to encounter. From these iterative experiences, infants gradually learn about the social information in their environment such that they become more attuned to the cues that promote social interaction and learning. In somewhat different terms, this is what Bertenthal and Boyer (Chap. 2, this volume) referred to as interactive specialization: 4-month-old infants were cued equally by a pointing hand and a foil, but 6-month-old infants were cued more effectively by a pointing hand. The implication is that infants' response to a pointing hand became more specialized with age and experience.

In addition, recent research is beginning to provide new details about how the visual information available to infants changes with age and experience (Jayaraman, Fausey, & Smith, 2015). Infants from 1 to 11 months of age who wore a head-mounted camera during daily activities showed a decline in their attention to faces during the first year. At the older ages, infants increased their attention to viewing hands (Jayaraman, Fausey, & Smith, 2013), which is consistent with the findings reported by Bertenthal and Boyer (Chap. 2, this volume). In sum, these changes in social attention do not reflect the unfolding of some genetic blueprint, but rather the continuing adaptation of a developing child to the social and cognitive demands of the environment.

Based on the evidence presented above, there is little doubt that infants receive a head-start in learning about social information, but it is an empirical question as to whether this learning is any way different from learning about objects. From the evidence presented by Shultz and colleagues, we know that infants who are later diagnosed with ASD fail to show the same preference for faces as typically developing infants. This departure from normative social experiences is believed to retard the development of successful social adaptation and as a consequence increase the likelihood of atypical outcomes. The intriguing question presented by this evidence is whether infants at risk for ASD would show more successful outcomes if they attended more to social information, or if the problem is compounded by an additional deficit in learning about social information.

8.4.2 Brain Localization

In considering whether social attention is specialized, it appears that some of the specific deficits revealed by individuals with ASD provide some of the most compelling evidence. According to Bush and Kennedy (Chap. 7, this volume), the research literature reveals that individuals with ASD show differences in responding to eye gaze as well as orienting to and scanning of faces, and scanning of social scenes more generally. Critically, the evidence on differences in neural activation of three brain regions (FFA, amygdala, and STS) that may underlie abnormal social attention is mixed and seems to depend on how much visual attention is directed to the face or eye region. This evidence thus calls into question whether social attention can be differentiated in terms of brain localization because social deficits associated with ASD cannot be attributed to the functioning of these brain regions.

Admittedly, the preceding evidence relating to localization is incomplete, which is why the neuropsychological evidence presented by Puce and colleagues (Chap. 4) is perhaps more relevant to the current discussion. They review a report of a patient with a circumscribed lesion involving the right superior temporal gyrus (STG) who could not correctly detect left averted or direct gaze. Critically, other directionally oriented stimuli, such as arrows, did not significantly affect performance (Akiyama et al., 2006). A similar behavioral dissociation was reported in 5 patients with amygdala lesions (Akiyama et al., 2007). This evidence should not, however, be taken to imply that the STG/pSTS is localized for processing gaze behavior, because the pSTS is also selectively active for other biological motions, such as mouth, hand, and leg movements. Interestingly, these findings are consonant with the views expressed in some chapters that social attention includes a wider range of actions than just gaze or facial expressions. An additional reservation about considering social attention processes localized in the STG/pSTS is that it is possible that the locus of the problem may actually reside in the white matter pathways that carry this social information to, or from, that region rather than a function of problems in the region itself. It is possible that the connectivity between the STG/pSTS and regions such as the amygdala and fusiform cortex (see Bush and Kennedy, Chap. 7, this volume) may be aberrant. This could arise because the white matter pathways have aberrant connections, or alternatively, that these three brain regions do not send properly coordinated signals between the brain structures making up parts of the social brain (see Stanley & Adolphs, 2013). Currently, studies of functional and effective connectivity are beginning to address these questions (e.g., Ethofer et al., 2013).

8.4.3 Domain Specificity

Lastly, we consider whether social attention is domain-specific, which is often defined as a specific class of information that constitutes the input to some perceptual mechanism or process. Critically, these inputs are inseparable from the psychological processes that operate on them, but the relation is not necessarily one-to-one because there could be multiple classes of stimuli that are processed the same way or there could be more than one process that operates on the same class of stimuli (Atkinson, Heberlein, & Adolphs, 2011). For example, faces and objects may be separate classes of stimuli, but they may be both individuated by the same process, such as an object file (e.g., Kahneman, Treisman, & Gibbs, 1992), or by different processes based on whether they are perceived configurally or featurally (e.g., Farah, 2000). Thus, domain specificity does not necessarily imply that orienting to social and nonsocial stimuli will be functionally different as will become evident in the following discussion.

As has been discussed repeatedly in this volume, humans possess remarkable social attention skills that involve eye gaze, head and body orientation, as well as pointing gestures (Langton, Watt, & Bruce, 2000; Nummenmaa & Calder, 2009). Extensive research over the past decade reveals that the eyes, in particular, convey a great deal of personal information and direct our attention to specific people, places, and objects (Birmingham & Kingstone, 2009). A good deal of this research has benefitted from the use of a spatial cueing paradigm (Posner, 1980). When a face is presented in the center of the screen prior to the onset of a peripheral target, detection is faster if gaze is directed toward the side where the target will appear (e.g., Driver et al., 1999; Friesen & Kingstone, 1998). The finding that these shifts in attention are very fast (ranging between stimulus-target onset asynchronies of 0 and 300 ms) and occur when gaze direction is not predictive or even counter-predictive of target location has been interpreted as reflecting an automatic, reflexive, and stimulus-driven (exogenous) orienting of attention which is very difficult to inhibit (Driver et al., 1999; Friesen, Ristic, & Kingstone, 2004; see Frischen, Bayliss, & Tipper, 2007 for a comprehensive review).

Once it was established that people follow central eye gaze cues automatically or reflexively, researchers began asking whether this response was specialized for social stimuli. Some neuroimaging studies indicated that shifts of attention triggered by either gaze or arrows rely on different neural structures (Hietanen, Nummenmaa, Nyman, Parkkola, & Hamalainen, 2006; Hietanen, Leppanen, Nummenmaa, & Astikainen, 2008), or at least engage the same areas differently (Tipper, Handy, Giesbrecht, & Kingstone, 2008). Likewise, Kingstone, Friesen, & Gazzaniga (2000) showed that reflexive orienting to eye gaze was lateralized to the right hemisphere in a split-brain patient, whereas no such effect was found using arrows (Ristic, Friesen, & Kingstone, 2002). Furthermore, two recent studies (Greene & Zaidel, 2012; Marotta, Lupianez, & Casagrande, 2012) demonstrated a right hemisphere specialization for gaze cues that was not present for nonsocial cues. Consistent with these findings, a few behavioral studies reveal a processing advantage for gaze cues relative to symbolic cues, such as arrows (Friesen et al., 2004; Ristic, Wright, &

Kingstone, 2007), but the majority of the evidence fails to support differential processing of gaze and a range of nonsocial cues (e.g., Brignani, Guzzon, Marzi, & Miniussi, 2009; Dodd, Stigchel, Leghari, Fung, & Kingstone, 2008; Hommel, Pratt, Colzato, & Godijn, 2001; Kuhn & Kingstone, 2009; Tipples, 2002, 2008). This finding is especially noteworthy given that the neuropsychological lesion studies of Akiyama et al. (2006; 2007) discussed earlier as well as the neuroimaging studies discussed above all suggest that gaze and arrow cues are processed by different neural structures. Nevertheless, there is scant behavioral evidence that orienting to gaze cues and arrows is different.

How can we reconcile evidence for dedicated processing of eye gaze by the brain with so little empirical support suggesting a difference in responses to gaze and arrow cues? One possibility is that symbolic arrows are omnipresent and overlearned by adults, and thus result in the development of automatic stimulus-response mappings (Kornblum, Hasbroucq, & Osman, 1990; Ristic & Kingstone, 2012) that offset the dedicated processing by the pSTS for gaze cues. A second possibility is that specialized attention to social stimuli may be more related to the selection than to the shifting of attention (cf. Birmingham & Kingstone, 2009). It is typically assumed that spatial orienting to social cues primarily involves shifting attention in the direction cued by the stimulus, but it is also necessary for the observer to first selectively attend to a stimulus before orienting attention in the direction cued by it. One problem with previous research using the spatial cueing paradigm is that it compares social and nonsocial stimuli on a dimension in which both stimuli are very similar—communicating the direction of a target (Gibson & Kingstone, 2006). Conceivably, differences in selective attention may be the key to differentiating between social and nonsocial stimuli, but the standard spatial cueing paradigm eliminates this process entirely because the stimulus cue is preselected for the participant (Birmingham & Kingstone, 2009).

Clearly, there is no definitive answer with regard to whether social attention is specialized. The answer depends as much on how the question is conceptualized as it does on the empirical data (Liu & Chaudhuri, 2003). Throughout this volume, authors have referred to the processes associated with social attention as complex. We would therefore like to conclude this chapter by summarizing the value of conceptualizing social attention as a complex dynamical system.

8.5 Social Attention from a Dynamical Systems Perspective

Social attention and interpreting others' actions are foundational to how we communicate, learn about the social and physical world, regulate emotions, and develop attachments with others. Disorders in social attention are associated with several neuropsychiatric disorders, including Autism, which has been increasing over time and now has a prevalence of one in 88 children by the age of eight years (Baio, 2012). These social processes begin to emerge at birth leading some theorists (e.g., Baron-Cohen, 1995) to suggest that they are primarily innate. Yet, recent research reveals that this conclusion is overly simplistic and neglects how developmental changes in social cognition are a function of an interactive specialization between maturational changes in the brain and specific experiences of the infant (e.g., Grossman & Johnson, 2007; Senju & Johnson, 2009). This research is also demonstrating that responses to social cues vary among individuals and even within an individual across time. Moreover, many other factors, such as social cognition or state or emotion regulation, contribute to interindividual variability, and thus make it extremely challenging to observe systematic changes across individuals (Rothbart & Derryberry, 1981). These complex interactions illustrate that social behavior cannot be investigated within a deterministic and stationary model of human development.

In spite of this evidence, the prevailing paradigm for studying the development of social attention is analysis by decomposition and investigations limited to studying the neural, autonomic, or behavioral systems one age and one measure at a time (Bertenthal, 2007). Research on human social behavior and emotion has been limited to hypotheses linked to one system at a time, such as the autonomic nervous system, specific regions of the brain, such as the STS or the prefrontal cortex, or hormones (cortisol) or neuropeptides (oxytocin or vasopressin). This piecemeal and fragmented approach to the study of social behavior results in incomplete and often inconsistent models. Paradoxically, many of these systems are interrelated in terms of both common structure and function. New research is needed to enable the development of more integrated neurophysiological and behavioral models of social attention and social cognition.

The study of social attention encompasses different models and methods, but virtually all posit that behavior can be analyzed by decomposing the problem space into static variables or systems that are linearly related to each other. Human behavior needs to be studied as a dynamical system. By definition, such a system is high-dimensional, multilevel, multicausal, and nonlinear (Bertenthal, 2007). A dynamical system approach provides useful tools for describing the time evolution of systems with many interacting degrees of freedom. Although the study of dynamical systems has had a long and venerable history in the physical sciences, it has yet to have a major impact in the psychological sciences (Ward, 2002). This seems somewhat paradoxical given that psychologists are interested in a wide range of phenomena that change over time, including learning, memory, thinking, and especially development.

What has been lacking in most studies is a way of modeling how behavior is dynamic and interactive, and how it unfolds over multiple time scales. For a number of years, one of us (B.I.B.) was involved in the development of the Social Informatics Data (SID) grid (Levow et al., 2007), which was a web-based test-bed for collecting real-time multimodal behavior at multiple time scales. Multimedia data (voice, video, images, text), time series from different sensors, such as motion analysis, EEG, etc., corpuses of written and spoken languages, behaviorally coded data, as well as survey data were all stored in a distributed data warehouse employing web and grid services that supported data storage, access, exploration, annotation, integration, analysis, and mining of individual and combined data sets. The goal

Table 8.1 A summary of the transformative effects of the SID grid infrastructure

	Today	Tomorrow with SID grid	Milestones
Theories and models	Static Single cause Linear Component processes Symbolic models	Dynamic Multiple causes Nonlinear Systems or networks Embodied models	
Collaboration	Single labs annotations by single investigators Local access only	Community of collaborators Collaborative annotation Remote and distributed access	Collaborative annotation tool
Query and analysis	Standard statistical analyses Single stream Nonstandard formats and coarse alignment Single location Standalone application	Automated query, exploration, and analysis services Multiple streams Tools to acquire, transform, and align multiple data streams Multiple locations Extensible SID grid application	Query and analysis services
Measurement and annotation	Single measure Unimodal Single time scale Manual coding	Multiple measures Multimodal Multiple time scales Automated coding	Multimodal data stream tool
Data collection	Single investigator populating database on single workstation	Community of Collaborators creating SID grid data resources on grid	SuperLab legacy data sets

was to stimulate multidisciplinary and collaborative research among diverse groups of researchers. As these goals are attained, it will transform how research is conducted. See Table 8.1 for a summary of what the developers of the SID grid consider the most noteworthy transformations.

If we are to continue to make progress in understanding the underlying developmental pathways and networks responsible for social attention in children and adults, then it is incumbent on us to begin exploring the complex and dynamic interactions that occur between neural, autonomic, hormonal, and behavioral systems during development and throughout adulthood. Although we are not the first to highlight this knowledge gap, this idea has not gained traction due to the many theoretical, methodological, and analytical obstacles to implementing this objective. Overcoming these obstacles requires the combined knowledge of multidisciplinary teams of researchers with expertise in social and affective neuroscience, social neurobiology, developmental science, social psychology, cognitive science, computer science, and computational neuroscience. By coordinating and complementing each other's knowledge and skills, these teams will be able to create a much more ambitious

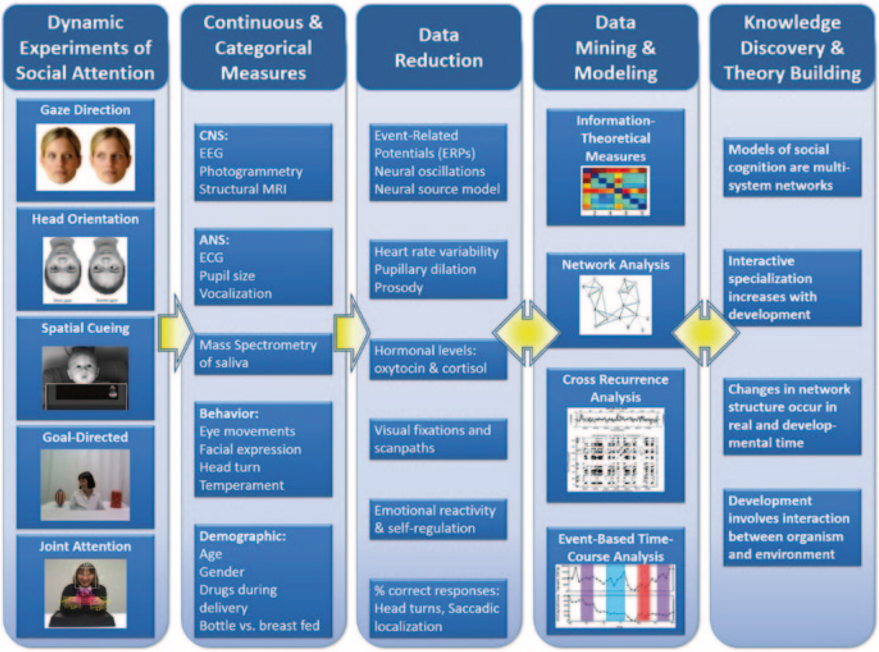

Fig. 8.2 Experimental workflow summarizing the complementarity *between* theories, models, and data. Dynamical stimuli and multimodal measures are displayed in the two *leftmost* panels. The *middle* panel focuses on data reduction and standardization. The two *rightmost* panels depict data analysis/results (including data mining and modeling) and knowledge gained/theory building, respectively

research agenda for the future. We have been involved along with a number of collaborators in developing such a research agenda for the study of the development of social attention, and this program of research along with its goals for contributing to knowledge discovery and theory development are summarized in Fig. 8.2.

As illustrated by the entirety of this volume, the study of social attention encompasses multiple models and methods, and it represents a multidisciplinary field of study, par excellence. The next step is to begin coordinating this multidisciplinary research into a more systematic program of research as exemplified by the type of workflow outlined above. It is our sincere hope that this book will have inspired some investigators to pursue this research agenda.

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