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Review

Social Attention: Developmental Foundations and Relevance for Autism Spectrum Disorder

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ABSTRACT

The use of the term "social attention" (SA) in the cognitive neuroscience and developmental psychopathology literature has increased exponentially in recent years, in part motivated by the aim to understand the early development of autism spectrum disorder (ASD). Unfortunately, theoretical discussions around the term have lagged behind its various uses. Here, we evaluate SA through a review of key candidate SA phenotypes emerging early in life, from newborn gaze cueing and preference for face-like configurations to later emerging skills such as joint attention. We argue that most of the considered SA phenotypes are unlikely to represent unique socioattentional processes and instead have to be understood in the broader context of bottom-up and emerging top-down (domain-general) attention. Some types of SA behaviors (e.g., initiation of joint attention) are linked to the early development of ASD, but this may reflect differences in social motivation rather than attention per se. Several SA candidates are not linked to ASD early in life, including the ones that may represent uniquely socioattentional processes (e.g., orienting to faces, predicting others' manual action goals). Although SA may be a useful superordinate category under which one can organize certain research questions, the widespread use of the term without proper definition is problematic. Characterizing gaze patterns and visual attention in social contexts in infants at elevated likelihood of ASD may facilitate early detection, but conceptual clarity regarding the underlying processes at play is needed to sharpen research questions and identify potential targets for early intervention.

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Looking at Hugues Merle's painting *Contes enfantines* (Figure 1), few would disagree that social attention (SA) occurs in the scene. The younger children look at the older girl's face with a magnetic intensity, completely absorbed by the words coming from her mouth, her gaze, and her facial expressions. The term "social attention" is typically used to describe phenomena linked to selective attention to eyes and faces, nonverbal social communication, and joint attention. The term is also commonly used when describing differences in looking behaviors in people with autism spectrum disorder (ASD) (1), and atypical SA has been suggested to represent a potential biomarker for the condition (2). A common assumption is that atypicalities in SA very early in life may be central for understanding early developmental trajectories in children with ASD (3). While looking in social contexts could potentially be facilitated by automatized SA processes in typical development, it may draw on different processes in ASD. This potential fundamental link to ASD and the general use of eye-tracking technology in (social) cognitive developmental neuroscience may explain why the use of the term "social attention" appears to be increasing exponentially in the literature (4).

Although theoretical discussions of the term "social attention" are scarce (4), 2 distinct views regarding the nature of SA can be identified in the existing literature:

Hypothesis A. SA is a domain-specific attentional process, distinct from other attentional processes. This view is implicated by research suggesting that it builds on highly specialized brain circuits (4,5), i.e., as a social parallel to the domain-general attentional networks that have been identified over the last few decades (6,7). A more extreme version of this hypothesis is that SA is both domain specific and unitary (across many ostensibly different SA phenotypes) (4), a possibility we will return to in the Discussion.

Hypothesis B. Attention allocation to social objects, events, and scenes can be explained by general attentional processes (Figure 2). These involve 2 interlinked types: exogenous (stimulus driven, reflexive) and endogenous (goal-directed, voluntary) orienting (8). Furthermore, attentional mechanisms that are spatially unselective (e.g., general alerting) can be differentiated from visuospatial orienting (6). In infancy, many looking behaviors reflect a blend of exogenous and emerging endogenous processes (9).

These 2 views represent the extreme ends of a spectrum of possibilities, including that SA becomes distinct from other attentional processes over time, driven by experience and interaction with social stimuli (4,10,11).

To improve clarity around these contrasting views on SA, this review presents and discusses specific phenotypes that have been termed SA in the past (hereafter referred to as candidate SA phenotypes) while briefly considering available evidence supporting either hypothesis A or hypothesis B described above for the phenotype in question. The candidates are selected based on their prevalence in the ASD and

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Figure 1. *Contes enfantines* by Hugues Merle (1823–1881).

developmental cognitive neuroscience literature. Because SA is thought to be tightly linked to ASD, which develops early in childhood, our focus is on developmental data from the first years of life. We also summarize the link, or lack thereof, to ASD early in life for each candidate SA phenotype. Whether a single SA candidate is affected in ASD is not in itself informative for evaluating hypothesis A versus hypothesis B. However, looking at the emerging pattern across several SA candidates could be informative for understanding the nature of SA (e.g., its unity) and ASD. If ASD is fundamentally linked to SA, we expect that the candidate SA phenotypes with the most support for hypothesis A will be particularly affected in infants who develop ASD symptoms.

Studies of SA have been criticized for their reliance on 2-dimensional stimuli shown on a computer screen (12–14). In this review, we also illustrate how researchers are increasingly using modern technology to assess infants in more ecologically valid settings to try to circumvent this limitation (15).

SA: THE CANDIDATES

Orienting to Faces and Preference for Social Information

The term social attention is often used when describing how individuals distribute their gaze to social versus nonsocial stimuli. Given our focus on early development in ASD, we have selected looking to faces, eyes, and mouths, but there are other examples of stimuli that belong to this category, including preferential looking to biological motion [for which the link to ASD below age 2 years is largely unexplored; see (3,17,18)] and the actions of others (19).

Candidate 1: Basic Orienting to Face-like Patterns. There is a robust body of evidence demonstrating a fast capture of attention by face-like patterns (Figure 3A) at birth and throughout the life span [e.g., (20–24)]. Such face orienting is reflexive and exogenously driven (22,23) and is thought to have a canalizing role in cortical specialization and perceptual narrowing (9,25–27).

It has been argued that newborn face orienting is the product of a domain-general process based on low-level stimulus characteristics [e.g., (25,28–32)], yet the prevailing view is that it represents a domain-specific social bias [e.g.,

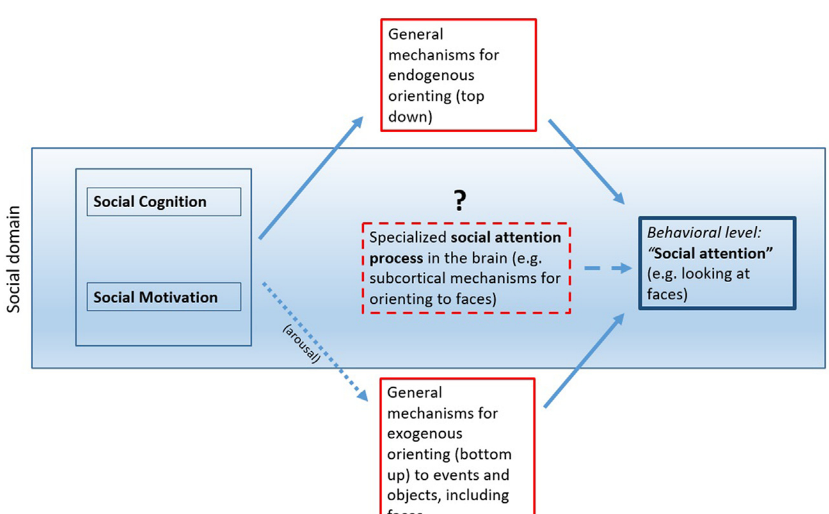

Figure 2. How social is social attention (SA)? The use of the term in the developmental and autism spectrum disorder literature often implies a specialized process for SA in the brain (central dashed box). According to an alternative view, behavioral instances of SA (rightmost box) can be explained by domain-general attentional processes (bottom, top). The figure provides a simplified overview of the main factors behind SA behaviors. It is not intended to provide a full overview of all possible links (e.g., bidirectional).

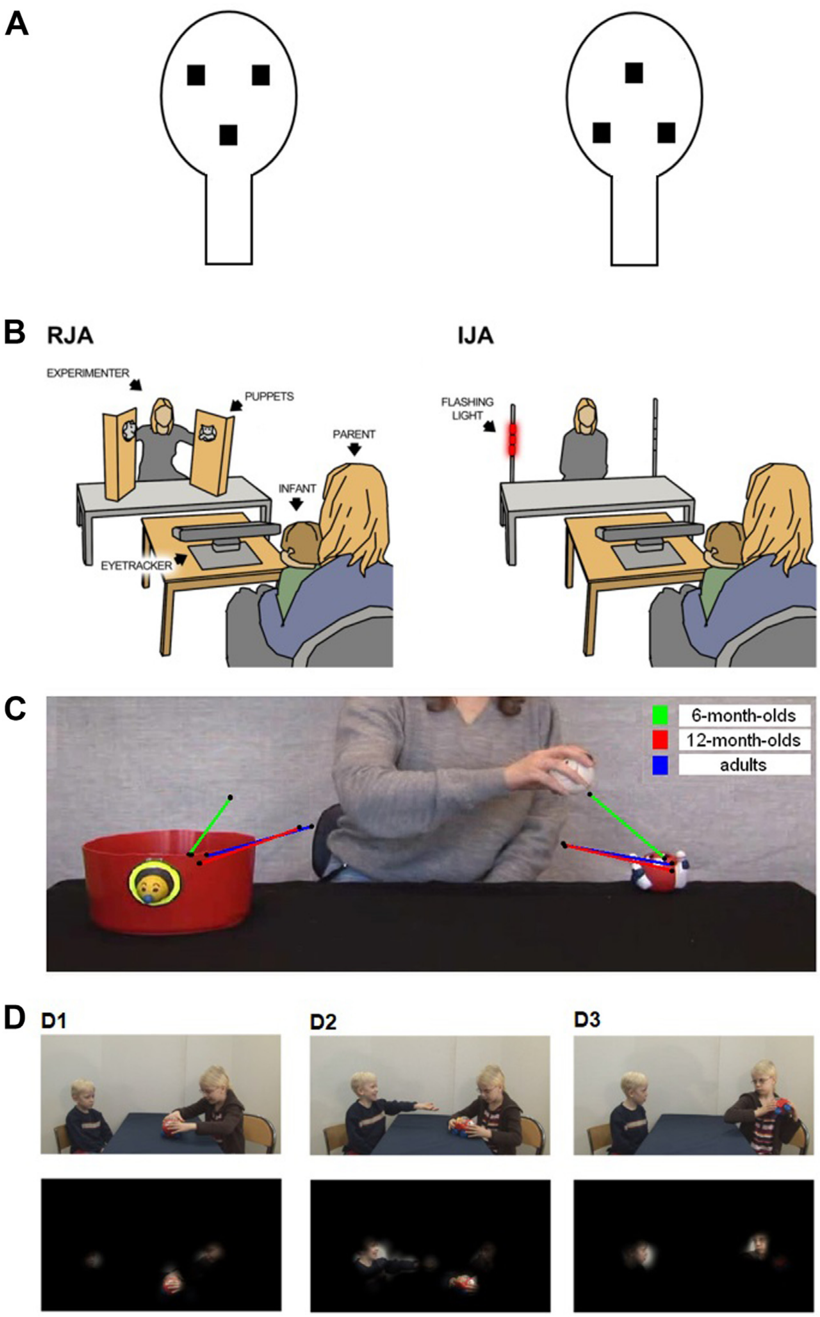

Figure 3. The many faces of social attention. **(A)** Human newborns prefer to look at stimuli with patterns that resemble the basic configuration of high-contrast areas of a face (left). Whether newborns with later autism spectrum disorder (ASD) display similar attentional patterns is not yet known. **(B)** Responding to and initiating joint attention, assessed in a live eye-tracking paradigm. [Reproduced with permission from Nyström *et al.* (49).] While children with ASD showed atypicalities in initiating joint attention (IJA), their tendency to follow gaze was like typical infant performance (responding to joint attention [RJA]). **(C)** Predictive eye movements used in action observation. When observing a model moving objects to a container, 6-month-old infants reactively track the moving object/hand. In contrast, 12-month-old infants and adults, who are able to perform such actions themselves, use goal-directed predictive eye movements, which is believed to tax their own motor system and representations of similar actions (113). The colored lines show the direction of eye movements when leaving the object area (right) and entering the goal area (left), respectively, illustrating the striking similarity between 12-month-old infants and adults, who do not follow the moving hand/object, but instead move gaze toward the goal area (bucket). Most data indicate that this basic predictive ability is intact in children with ASD (119). Data are replotted based on Falck-Ytter *et al.* (111). **(D)** Attending to complex and dynamic social scenes involving a nonverbal video-recorded interaction between 2 children. In the video, the girl refuses to give the object to the boy despite his request. The top row shows the full stimuli, and the bottom row shows how typically developing 6-year-old children tend to attend to this scene. The final frame **(D3)** illustrates how virtually all typically developing children quickly moved their gaze to the face of the girl after the boy's (neglected) request. The tendency to do so was significantly weaker in ASD (area under the curve $>$ 0.85). [Reproduced and adapted with permission from Falck-Ytter *et al.* (143).] This result indicates that analyses that take the timing of gaze shifts into account may provide insights that are not captured by aggregated looking time measures.

(26,33)] hypothesized to be generated by a subcortical processing route that includes the superior colliculus, pulvinar, and amygdala complex (26). The existence of a specialized and very early-emerging face orienting mechanism is supported by one report of preferential head turns to face-like stimuli in fetuses during the third trimester [(34); but see (35)] and by a recent finding that newborn brain responses to face-like patterns recruit an adult-like face-specific cortical circuit (36).

Available evidence suggests that this basic face bias is no different in infants with a later ASD diagnosis (37) or in autistic adult individuals (22), although one study found that it was decreased in preschoolers with ASD (18). In the infant study, Elsabbagh *et al.* (37) measured 6- to 10-month-old infants' tendency to orient to faces among nonface distractors presented on a computer screen. All groups, including infants who later met the criteria for an ASD diagnosis, tended to move their gaze to faces in about 50% of trials, high above the level expected by random gaze allocation (20%). Notably, no study has examined whether face orienting is typical in newborns with later ASD.

Candidate 2: Preferential Looking to Naturalistic Faces in More Complex Visual Displays. From around 4 to 6 months of age, infants' sustained face preference also reflects top-down control (37–40). Thus, older infants' face preference and consequential emerging face expertise are the products of both unique SA orienting biases and multiple other attentional and executive abilities (26,27,29,41). Face preference (when in competition with nonsocial objects) already has a substantial contribution from genetic factors at 5 months [heritability of 0.46, (42)], implying that infants select social versus nonsocial input partly due to their genetic predispositions (43).

Looking at nonfacial body parts and nonsocial objects and events represents adaptive behaviors that are expected to dominate during certain age periods (18,44). This complexity may explain the mixed findings with regard to face preference in ASD. Some studies have shown that infants and toddlers later diagnosed with ASD look at faces longer than infants and toddlers in control groups do (37,45,46), with the investigators hypothesizing that this indicates slower maturation of attention control in ASD. Other studies based on screen-based eye tracking and video recordings from homes (47,48) have suggested shorter looking time to faces during the first 2 years of life in infants with later ASD, while a recent live eye-tracking study found no clear group differences in terms of face preference (49).

Candidate 3: Preference for Specific Facial Parts (Eyes and Mouth). A bias to attend to faces with direct as compared to averted gaze is seen shortly after birth (21), and preferential looking to the eyes over other facial features is seen throughout the first half of the first year (50–52). Neurophysiological responses from infants elicited during the earliest time stages of visual attention that are sensitive to the presence of whole faces are equally, or even more strongly, elicited by images of eyes alone or among nonsocial objects (53,54). While these results demonstrate that eyes are prioritized during visual processing, it is not clear whether this effect is driven by unique attentional mechanisms underlying attention to eyes rather than by orienting to faces per se (i.e., candidate 1).

Toward the end of their first year when infants are in an intense phase of language learning, they tend to increase their looking to the mouth (vs. eyes), which provides rich audio-visual speech information (50,51,55,56). During the second year of life when infants have gained some native language experience and narrowed their perceptual expertise, their preference for eyes increases again. Individual differences in mouth (vs. eyes) preference are substantial, and recent twin data suggest that this variability has a moderate-to-high contribution from genetic influences at 5 months (52) and at 21 months (57) of age.

Regarding infants later diagnosed with ASD, results are mixed, probably reflecting age differences as well as other study-specific factors (47,58). A small effect of decreased looking to the mouth has been found in a meta-analysis of attention in children with diagnosed ASD (59). Eye- versus mouth-looking has not been evaluated in an ecologically valid context in infants at elevated risk for ASD [but see ref (60) for a study of school-aged children].

Phenotypes Linked to Joint Attention

Joint attention refers to the triadic sharing of attention between 2 individuals toward a common object or event (61,62). Here we review 3 SA candidates of increasing complexity that are linked to this concept.

Candidate 4: Gaze Cueing. Gaze cueing refers to the tendency to orient faster to peripheral stimuli appearing in locations previously cued by other people's eyes. Gaze cueing is present across the life span (including in newborns) (63–66) and is typically seen as an exogenous form of attention cueing subserved by activity in the anterior superior temporal sulcus (67). Gaze cueing has been suggested to indicate the presence of a specific sensitivity to spatial information conveyed by eyes (63). This view was challenged by the finding that arrows produce a similar cueing effect (68). However, later studies have indicated that attention cued by gaze is more strongly reflexive (and less amenable to top-down processes) than attention cued by arrows (69–71), thus supporting the hypothesis that eye gaze has a special status compared with nonbiological cues and is potentially supported by a distinct neural network (72).

To our knowledge, gaze cueing in infants who later receive an ASD diagnosis has not yet been investigated. In children with a confirmed ASD diagnosis, results are mixed (73–79). Both Senju *et al.* (80) and Chawarska *et al.* (81) found typical gaze cueing in autistic children but reported more subtle differences between these children and typically developing children in terms of their responses to gaze cues versus nonbiological cues (e.g., arrows). This may reflect dissociable underlying processes (82), a view supported by a functional magnetic resonance imaging study (83).

Candidate 5: Gaze Following. Gaze following refers to the tendency to respond to changes in others' gaze by looking in the same direction. In contrast to gaze cueing, gaze following is not exogenously triggered by changes in peripheral stimulation. Gaze following emerges around 3 to 4 months of age (84), coinciding with a period of intense development of cortical control over eye movements (85). Gaze following then gradually becomes faster (86) and more accurate (49) during infancy and early childhood. Gaze following plays an important role in language development and learning (87–89). In adulthood, gaze following is associated with activity in several areas of the medial prefrontal cortex as well as the right posterior temporal sulcus (90–92). Gaze following in infancy is associated with partly similar brain activation patterns (93,94).

The ability to follow gaze reflects several processes, such as attention to eyes and faces and the ability to disengage attention. It has been argued that gaze following in very young infants may rely on the perceived motion of the head or pupils [e.g., (66,95)] and that nonbiological moving objects may evoke a similar response (96). One recent study indicated that young infants' gaze following is affected by both social cues (direction of looking) and nonsocial cues (general movement), but that gaze following comes to rely more on social cues with increasing age (97).

Live observational studies of gaze following early in life in ASD tend to find group differences (98–101), but these findings are not replicated in eye tracking studies using prerecorded stimuli (102–105). This suggests that screen-based methods could fail to capture some important element of the interaction (106). However, using a live eye-tracking approach (i.e., real interaction with another person) (Figure 3B), Nyström *et al.* (49) recently found that infants with later ASD were equally likely to follow gaze as infants without subsequent ASD. Thus, impaired gaze following per se does not stand out as a clear early marker of ASD.

Candidate 6: Initiation of Joint Attention. Infants' gaze is not just an information gathering device. Because eye movements are visible to others, the use of gaze is also a key component of their nonverbal communication, e.g., with parents (43,49,107). Toward the end of the first year, infants begin to use gaze behaviors that can initiate joint attention episodes with others (49). Specifically, around 8 to 9 months of age, infants start looking back and forth between an object that has caught their attention and another person, a behavior referred to as alternating gaze (88). At 10 to 13 months, more overt behaviors, such as pointing, start to emerge (88,108). Initiation of joint attention (at least in adulthood) specifically recruits reward-related brain areas linked to social motivation, such as the ventral striatum, suggesting involvement of top-down attentional control (92). The same brain areas are not typically activated during more reactive gaze following.

Children with ASD use gestures such as pointing and showing less often than typically developing children [e.g., (98)], and infants later diagnosed with ASD have been shown to engage less in alternating gaze than typically developing infants as early as 8 to 10 months of age (49,109). Compared with gaze following, impairment in initiation of joint attention in children with ASD appears to be both more pronounced and long-lasting (110).

Attention During Observation of Other People's Manual Actions

Although gaze performance during action observation can be seen in part as a special case of preferential looking to social information (similar to preference for faces; see above), evidence suggests that manual actions give rise to a special type of eye movements that deserve a separate discussion.

Candidate 7: Predictive, Goal-Directed Eye Movements. Real-time, predictive eye movements to goals during action observation emerge toward the end of the first year in infancy (111,112) (Figure 3C) and, at least in adults, depend on a somatotopic recruitment of the observer's motor system (113). It is believed that observers recruit their own action plans during action observation to predict other people's action goals (114). According to one interpretation of the literature, this action mirroring is a highly automatic process ("direct matching") not requiring top-down control (115,116). If correct, these eye movements may reflect low-level SA processes that are triggered specifically by hand-object interactions. According to an alternative re-enactment view, motor recruitment happens after the observer has understood an agent's intention (115). However, the latter view cannot explain why predictive eye movements are typically not observed when infants look at self-propelled objects moving toward target objects, even though they do attribute goals to such events (116). Although both predictive abilities in general and perception-action mirroring have been proposed to be atypical in ASD (117,118), the available data from young children and infants at elevated risk do not indicate substantial group differences, if any (119–121). It appears as if the distinction between live versus screen-based eye tracking is not crucial for this phenotype because it is observable in both contexts in infancy and adulthood (111,112,114).

DISCUSSION

In the literature on basic attentional processes, careful experimentation over many years indicates that the underlying neural systems are anatomically separate from other information processing systems and that multiple distinct attentional systems exist (6). How SA fits into this picture has not been altogether clear. Our review indicates that there is no unequivocal support for the involvement of unique socioattentional processes (see hypothesis A) (Table 1) for any of the SA candidates. For example, there is no consensus in the field that joint attention behaviors such as gaze following and alternating gaze (Figure 3B), very often referred to as reflecting SA in the literature, involve distinct social attention processes in this sense. In fact, during joint attention and when looking at complex social scenes more generally (e.g., Figure 3D), top-down influences (reflecting past experiences, social motivation, mentalizing, and other forms of social cognition) are likely to play a major role in moment-to-moment gaze allocation. This may explain why visual saliency models (122) tend to fail to predict attention in such contexts (123). However, for some SA behaviors there is partial support for domain specificity and uniqueness at a mechanistic level. Prediction of other people's action goals (Figure 3B) appears to reflect a unique [at both behavioral and brain levels (113)] process linked to perceptual selection that requires social input to be triggered (111,114).

Table 1. Overview of Reviewed Social Attention Phenotypes

Candidate Number	Candidate	Support for Hypothesis A vs. B	Atypical in Infants With Later ASD?
1	Basic orienting to face-like patterns	Leaning A	No (but not yet studied in newborns)
2	Preferential looking to naturalistic faces in more complex visual displays	Leaning B	Mixed findings
3	Preference for specific facial parts (eyes and mouth)	Leaning B	Mixed findings (age-dependent)
4	Gaze cueing	Inconclusive	Not yet studied in infancy
5	Gaze following	Inconclusive	Mixed findings (methods-dependent)
6	Initiation of joint attention	Leaning B	Yes
7	Predictive, goal-directed eye movements	Leaning A	No

ASD, autism spectrum disorder.

Similarly, newborn orienting to face-like configurations (Figure 3A) is considered by many [but not all; see (25,28–32)] to constitute a uniquely social attentional process operating early in life (26,33).

How fundamental are SA differences in the development of ASD? Currently, there is no evidence available to suggest that SA behaviors that may be considered strong candidates in a mechanistic sense, such as action prediction (116) or orienting to faces (37), are atypical in infants with emerging ASD. In fact, the relatively few studies that have reported evidence supporting atypical SA behaviors (other than initiation of joint attention; candidate 6) during the first year of life in infants later diagnosed with ASD tend to have modest effect sizes or small sample sizes (47,58,124). However, it is worth noting that some SA behaviors, such as gaze cueing, orienting to biological motion, and orienting to faces, have not yet been probed in relation to ASD during the first few months of life. The fact that initiation of joint attention in infancy shows a relatively strong relation to later ASD could be consistent with the social motivation theory of ASD, which states that interaction and communication impairments in ASD stem from a reduced intrinsic reward value of social interaction for individuals with ASD as compared with typically developing individuals (125). Although it is questionable whether atypical gaze behaviors during social interaction in ASD reflect differences in domain-specific attentional functions per se, they may still be important because they could alter child-parent interaction dynamics and developmental trajectories.

We have focused our review mainly on the question of whether specific SA behaviors reflect unique socioattentional processes, i.e., processes that are distinct from general attention and from nonattentional processes such as social motivation and social cognition (Figure 2). An arguably more extreme interpretation of SA is that it is also unitary (4). The wide range of behaviors referred to as SA [ranging from basic biases, present at or even before birth (34), to highly dynamic gaze behaviors (Figure 3)], their different developmental trajectories, and their differential links to ASD speak against strong claims of unity (but notably, a differential link to ASD for early vs. later emerging SA behaviors does not per se exclude the possibility that SA is unitary because it could be linked to the timing of gene expression in children with the condition). It is likely that correlations across different SA phenotypes would emerge because they are similarly modulated by the social context in the same individual, e.g., via social motivation or general attention.

Despite the reservations mentioned previously regarding the SA category, one could argue that it is a useful umbrella term under which one can organize a set of related research questions. For example, some types of early SA phenotypes are associated with later social developmental outcomes (42,49) and thus are important to study irrespective of the exact biological/psychological underpinnings. However, more conceptual and methodological clarity is needed for progress at both a basic and an applied level. Studying looking at social objects and events with an eye tracker does not necessarily mean that what has been measured is best described as SA.

It is likely that differences in infants' gaze behaviors in social settings partly reflect genetic differences in the population (42,43,52,57), meaning that selection of visual input to some extent is rooted in genetics (active gene-environment correlation). Furthermore, because the eyes are visible to others, these differences could in turn affect caregiver responses toward their offspring (evocative gene-environment interplay).

Lately, interest in SA has spread to many other neurodevelopmental and child psychiatric disorders partly phenotypically overlapping with ASD, including social anxiety disorder (126,127), attention-deficit/hyperactivity disorder (128), and even anorexia nervosa (129). Behavioral inhibition is a temperamental precursor of social anxiety that can be detected in infancy (130). Longitudinal studies of SA behaviors in infants with behavioral inhibition could be informative about the role of emotional reactivity and regulation in relation to specific SA behaviors. Similarly, studies of different SA behaviors may compare developmental trajectories in infants with (later) autism versus attention-deficit/hyperactivity disorder (16) to understand the role of more general attentional atypicalities. Furthermore, studying SA behaviors in disorders with a known genetic cause can inform us about the underlying biological mechanisms and thus potentially identify stratification markers for ASD. Infants with fragile X syndrome look at other's faces less often than typically developing infants do, mirroring the adult literature from the condition (131) and also seemingly consistent with the high prevalence of ASD in the condition (132). In contrast, although between 70% and 90% of children with Smith-Magenis syndrome have symptoms consistent with an ASD diagnosis (133,134), preliminary evidence suggests that SA is relatively spared in infants with Smith-Magenis syndrome (135) and even enhanced at school age (136). Infants with Williams syndrome (whose personality later in life is often described as hypersocial) have atypically high levels of attention to faces (137).

Ecologically valid studies of SA phenotypes have mostly been conducted in older individuals, but distinct processing during passive social observation versus reciprocal interaction could emerge early (13) (but see candidate 7). As such, and as exemplified by the recent live joint attention eye-tracking study of Nyström *et al.* (49), more work needs to be done to characterize and validate SA behaviors (and potential atypicalities in ASD) in real-life contexts early in life (107). New analytic approaches that take into account the dynamic and bidirectional nature of everyday social stimuli and contexts may reveal more distinct underlying processes than aggregated looking time measures based on passive viewing (Figure 3C, D). Most studies aiming to measure SA have focused on visual attention. This has also been the focus in this review, but it is important that future research expands to include nonvisual modalities. Experiments specifically addressing attention to social auditory cues in ASD early in life are few [but see (138,139)]. To comprehensively address the questions of SA domain specificity and unity from a developmental perspective, it would be important to collect multiple SA candidate measures together with carefully assessed contrast phenotypes longitudinally over time. Furthermore, studies that compare different types of attentional functions (e.g., orienting and disengagement of attention) during processing of social and nonsocial stimuli, beyond examining gaze allocation, are likely to provide more definitive answers that advance the field. It is important to keep in mind that although a phenotype may recruit a domain-specific process at the group level, individual differences in this phenotype (or case control differences for ASD) may reflect other processes influencing the phenotype in question. In terms of intervention research for ASD, a better understanding of the nature of SA atypicalities is needed to develop better support and intervention programs (140,141). These will necessarily differ depending on whether atypicalities are reflected in social understanding, in social motivation, or in lower-level attention (Figure 2). Relatedly, because gaze differences in ASD may be adaptive responses to other, more fundamental information processing or motivational biases (142), it is not self-evident that it is meaningful, or even ethical, to target such behaviors in intervention trials.

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