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The directed attention model of infant social cognition

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During infancy, humans have a limited attention span, a limited working memory and an initial lack of social experience. Given these constraints, why are infants so socially competent and how are they capable of processing such complex social information? Here we present an information-processing hypothesis that may account for these early social capacities. We outline those aspects of the social situation that must be processed for the infant to respond in a socially appropriate manner. We also outline potential cognitive sequences through which this information is processed. We conclude that the infant uses social information to determine what is relevant in the environment and in doing so, the infant uses each successive aspect of the social world to filter the overall amount of available information to a manageable size.

INTRODUCTION

Over the past twenty years, research into infant social-cognitive capacities has shown that they have some remarkable social abilities, such as the ability to imitate others, even during early infancy. Infant social

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competencies are surprising given the complex, continuous and dynamic nature of other humans and their actions. Indeed, it has even been suggested that there are no environmental sources as complex as another person (Gallagher et al., 2000). The aim of this paper is to explain these skills while reconciling this with the infant's limited information-processing abilities.

Although models of social-cognitive processes have made important contributions to adult behavioural research on social-cognitive capacities (e.g., Chaiken & Trope, 1999), there have been few frameworks available for understanding early development. In fact, such models have been surprisingly absent from theorizing about the developmental bases of social perception. This may have been due to an initial need to map the parameters of infant abilities at different developmental stages before such models could be proposed. Alternatively, infant social cognitive capacities may have been interpreted in a wider and more established framework, such as Piaget's model of cognitive development (see, for example, the discussion of infant social-cognitive capacities in Anisfeld, 2005).

Adult models of social cognitive abilities have greatly informed research by providing new, testable hypotheses based on the rationale of the model. These hypotheses may not have been generated had not the model been applied. Two particular frameworks have come to the fore in adult research: dual-process models and social learning theory. First, dual-process models have been used whereby implicit and explicit processes are separated in terms of functional properties. The fundamental notion underlying these models is that some perceptual processes are rapid and require little effort, whereas others require concerted effort. For example, detecting someone's eye gaze is relatively automatic when compared with processing another person's motivations. Dual-process models are deliberately simplistic, however this is perhaps their strength (see, for example, Satpute & Lieberman, 2006, for a cognitive neuroscience perspective). An issue for developmental researchers is that these models do not consider how "implicit" operations may not be so automatic and simple to execute for an infant.

The second framework that has influenced social cognitive research with adults is social learning theory (SLT; Miller & Dollard, 1941). This theory, derived from behaviourism, is most often applied in clinical research (Bandura, 1977). It contains three basic notions. First, that human beings are evolutionarily designed for sensitivity to response consequences such as rewards or punishments. Second, that vicarious learning exists, whereby learning can occur by observing another person. Third, an individual is most likely to perform behaviours that the individual has observed performed by others with whom they identify. One primary drawback of SLT for developmental research is that the theory does not provide testable hypotheses in terms of developmental processes. Due to its behaviourist origins, it makes no distinction between an infant with a limited memory capacity and an adult with a wealth of experiences from which to draw contextual knowledge.

Infant working memory capacity has been shown to be relatively poor. This is in stark contrast to infant general capacities in the social domain. For example, Ross-Sheehy, Oakes, and Luck (2003) found that visual short-term memory rapidly changed over infancy, however skills by 13 months of age were still limited. In their preferential looking paradigm, infants viewed changing and nonchanging stimulus streams. Infants looked longer when they could recall the colours of the squares from the first presentation and if they changed in a subsequent presentation. Four- and six-month-olds only looked longer when a one-object stimulus stream changed colour. However by 10–13 months, infants could detect changes in displays with 2–3 items. When these capacities are compared with the number of components in a triadic interaction, there is clearly some form of differential processing occurring between those components of visual working memory and those cognitive processes involved in social situations. For instance, 3-month-old infants can process relations between themselves, an object and another person (Striano & Stahl, 2005). From an information-processing viewpoint, the social situation is clearly more complex than the task demands required in the visual working memory study.

In order to explain how infants exhibit complex social responses despite limited attentional resources and working memory capacities, we propose an information-processing account of how an infant may attend preferentially to key factors in the environment that are relevant for the social situation. This framework, termed the directed attention model, is based on known social-cognitive abilities of infants. For example, when posed with the question: "What needs to be processed in a social situation for socially appropriate responses to occur?", we can proceed to dissect the perceptual stages needed before the infant discerns enough of the environment in order to produce a socially correct behaviour.

We propose that the following key groupings of cognitive tasks must occur in order for the infant to successfully react to the social situation: (Stage One) the detection of socially relevant organisms; (Stage Two) the identification of socially relevant organisms; (Stage Three) assessment of the locus of attention and direction of eye gaze of the observed individual in relation to the infant; and (Stage Four) detection of any object-directed attention or object engagement by the observed individual. If these four components of the social situation are assessed, then the infant can: (Stage Five) infer the observed goal, and/or, prepare an appropriate response (e.g., establish contact, offer response, etc.). Each component will be briefly discussed, below, in terms of research into infant perceptual and cognitive abilities, together with how the model can explain infant social capacities at some ages.

STAGE ONE: THE DETECTION OF SOCIALLY RELEVANT ORGANISMS

The first thing that an infant needs to do in order to produce social responses is to detect those components of the environment that are socially relevant. Many studies have indicated that infants are sensitive to distinctions between animate and inanimate objects (e.g., Mandler & McDonough, 1996; Poulin-Dubois, Lepage, & Ferland, 1995). These studies suggest very early capacities to discriminate animate and inanimate objects in terms of the classification of motion, such as its regularity and energy source. Movement alone does not confer animacy.

Even though movement in peripheral regions of the visual field induces reflexive gaze orientation by humans, these cues can only tangentially assist in the detection of conspecifics. Many other aspects of the natural visual world move, such as most flora during a breeze. Infants must therefore be initially faced with the task of discerning movement that is biological from movement that is not biological.

The detection and interpretation of biological motion is critical for recognizing conspecifics (Bertenthal, Proffitt, & Kramer, 1987). Behavioural research suggests that humans detect and interpret biological motion very early in development, as shown by a preference to attend to biological motion when compared with stimuli depicting other forms of motion, such as randomly drifting dots. Much behavioural research has been conducted on infants' perception of biological motion, depicted by points of light moving as if attached to the major joints and the head of a moving person. Such stimuli, known as point-light displays (PLDs), convey little information regarding the schema of the underlying object or agent. Indeed, adult observers fail to report any relationship between static PLDs and the percept of a person. However, moving point-lights are perceived as depicting a human form in less than 0.5 seconds (Johansson, 1973). Three- and five-month-old infants discriminate these same moving point-light displays from ones in which the temporal patterning of the lights are perturbed. This is true even when the perturbation includes the same inter-relational mathematical vector translations as undisrupted PLDs (Bertenthal et al., 1987; Proffitt & Bertenthal, 1990).

It has been conjectured that multiple processing constraints, including stored knowledge of the human form, contribute to the interpretation of point-light displays throughout ontogeny (Bertenthal, 1993). This supposition is supported by findings indicating that 5-month-old infants do not discriminate point-light displays depicting unfamiliar agents, such as a four-legged spider, from a perturbed version (Bertenthal & Pinto, 1993). When combined, these studies indicate that experience of observing biological motion is required in order for infants to discriminate it from other forms of motion. Nonetheless, given that 3-month-olds have some capacity to discriminate biological motion from other types of motion, this suggests some very early capabilities. Furthermore, research investigating neural correlates to the perception of biological motion suggest that at least by 8 months, infants process at least some types of biological motion in a manner similar to adults at the neural level (Reid, Hoehl, & Striano, 2006). We consequently suggest that the detection of biological motion is of high importance for detecting conspecifics and that this process is required in order for the identification of the specifics of the social interaction.

STAGE TWO: THE IDENTIFICATION OF SOCIALLY RELEVANT ORGANISM

In our model, once the detection of biological motion has taken place, it would be beneficial to identify the specifics of the observed organism. This could occur as identification of species or an identification of an individual conspecific. Surprisingly, little work thus far has addressed the issue of infant sensitivity to human biological motion relative to biological motion produced by other species. However, much work has been conducted on how an infant discriminates between a familiar person, such as the mother, and an unfamiliar person. However, this research is almost exclusively focused on how infants process faces rather than how they discriminate the person—body and face inclusive—as a whole relative to another person. Even though an extensive review of this literature is not in the scope of this article, we will briefly summarize some key findings.

Perhaps most importantly, newborn infants can discern individual people and differences between people. Utilizing a preferential looking paradigm, Bushnell, Sai, and Mullin (1989) found that even a few hours after birth, newborn infants preferentially attended to their mother's face. It has been proposed that this early capacity to identify individuals is not the same as that possessed by adult humans, with the possibility that subcortical mechanisms are utilized before 3 months of age, whereas cortical regions process this information at later ages (Nelson, 2001). The early mechanism is conjectured to be less adaptable in terms of reconciling new visual information with previously stored representations.

Electrophysiological work with older infants suggests some capacities to discriminate familiar and novel people. de Haan and Nelson (1999) presented 6-month-old infants with a photograph of their mother and a stranger and with familiar and unfamiliar objects. They showed evidence for a familiarity effect. The resultant event-related potential negative component (Nc) was larger in amplitude for familiar faces than that for unfamiliar faces. Subsequent research into the functional properties of the Nc suggests that it is a robust index of infant attention (Richards, 2003). The results of de Haan and Nelson (1999) therefore suggest differential processing of familiar and unfamiliar conspecifics as well as suggesting an increased allocation of attentional resources when viewing familiar faces. As the Nc is maximal in amplitude at around 400 milliseconds, this suggests rapid encoding of key components of the human face in order to discriminate familiar from unfamiliar people.

STAGE THREE: ASSESSMENT OF THE LOCUS OF ATTENTION

Once the detection and identification of an organism has occurred, we speculate that the observing infant will attend towards characteristics that index the locus of attention of the observed organism. In the human face, this can be detected by observing the orientation of the eyes (Farroni, Csibra, Simeon, & Johnson, 2002) and the orientation of the head coupled with the orientation of the eyes (see Farroni, Johnson, & Csibra, 2004). Research into how infants determine the orientation of the entire human body has not been investigated. This is most likely due to the need to reduce the number of variables involved for an effective experimental design. However, we contend that if the observed individual is not oriented towards the infant, then it is likely that the individual is not intending to engage with the infant in a social manner and that this will be detected by the infant. Interestingly, once interaction has been established, then brief breaks in mutual gaze do not appear to influence the infant's understanding of a mutually enabled interaction (Nadel, Carchon, Kervella, Marcelli, & Réserbat-Plantey, 1999). This underlines the point that infants are highly predisposed to communicate, reciprocate and connect with other people (Striano, 2004; Trevarthen, 1979).

The human infant's discriminative abilities are highly robust with respect to elements of the human face that delineate the locus of attention. For example, Farroni et al. (2002) showed that newborn infants can discriminate between a face with eyes oriented towards the infant and eyes oriented away from the infant. These authors also demonstrated that 4-month-old infants differentially process faces with direct vs. averted gaze and that this is processed rapidly (c. 250 ms) after faces are presented to infants.

A first step in successful communication is understanding when a social signal is directed at and intended for the self. In adulthood, specialized brain regions activate when a social signal is detected. When an adult hears their name or are the visual target of someone's direct gaze, the paracingulate cortex and temporal poles activate (Kampe, Frith, Dolan, & Frith, 2001). Regardless of modality (auditory or visual) the adult brain is ready to detect another's intention to communicate. Newborns are sensitive to faces, voices, and eye contact (Rochat & Striano, 1999), but do not appear to have particular social expectations or show reduced attention or affect towards a social partner who suddenly stops interacting. However, with only six weeks of interactive experience infants show a classic still-face effect (Bertin & Striano, 2006). They reduce their smiling and gazing and then attempt to re-engage the social partner when suddenly still. Also by this age, infants distinguish between an adult who interacts in a relevant way by providing contingent feedback such as smiles and vocalizations compared to someone who interacts in an irregular way, with delayed social feedback (Striano, Henning, & Stahl, 2005).

These studies summarized here suggest robust social capacities in the domain of determining the locus of another's attention. Should the infant process this information, further socially relevant components of the environment can be determined. Through removing elements of the environment that are not socially relevant, the infant has effectively filtered extraneous information, thereby enhancing the chance of a correct discrimination of further components of the social situation.

STAGE FOUR: DETECTION OF OBJECT DIRECTED ATTENTION

Recent studies into eye gaze cuing and object processing suggest an early capacity for discerning a relationship between a person and an object. In one study, 4-month-old infants watched a video presentation of an adult gazing toward one of two objects. When presented with the same objects a second time, infants gazed toward the uncued object significantly more—suggesting that it was more novel (Reid & Striano, 2005). This suggests that 4-month-old infants not only followed the gaze of the adult, but acquired information about the object that was the focus on the adult's attention. In one study investigating the neural correlates of observing eye gaze on object processing, infants viewed an adult's face on-screen, and the eyes of the adult gazed toward an object. In the test trials, infants viewed the objects a second time. Infants exhibited enhanced neural processing (indexed by an enhanced positive slow wave) of the uncued object during test trials (Reid, Striano, Kaufman, & Johnson, 2004). Thus, the cued object was more highly processed when the face and object were on the screen and was subsequently more familiar to the infant when presented a second time than the uncued object.

The results of these experiments suggest that by 4 months of age infants use the gaze of an adult to facilitate attention to a location. This in turn biases processing of information from that location relative to objects in other locations. Objects in uncued locations are therefore inherently more novel for infants than objects in cued locations. In recent research investigating the neural correlates of joint attention in 9-month-old infants, it has been shown that infants allocate significantly more attentional resources to objects that are the subject of joint attention interactions relative to objects that are not involved in joint attention situations (Striano, Reid, & Hoehl, 2006). This result suggests that infants increase attention to aspects of the environment that are more socially salient.

These results are perhaps the most compelling support for the directed attention model of infant social cognition. These data demonstrate that infants use others as tools with which to reduce the amount of information available for them to process in the surrounding world. To this extent, they fit very well with the notion that infants direct their limited attentional resources and memory capacity to components of the world that are important for social relations.

STAGE FIVE: INFERENCE OF GOALS AND/OR PREPARE RESPONSE

Infants are capable of detecting and identifying others. They also have skills at remarkably early ages in determining the locus of another person's attention as well as their relationship to external components of the world, such as objects or locations. However, the ability to infer goals appears not to develop until the beginning of the second half of the first postnatal year. We suggest that infants are capable of processing intentions and goals only when earlier perceptual processes of the social environment have been resolved.

Much research suggests that markers of intentionality throughout human action may be critical to understanding goal direction. At least by 9 months infants are capable of discerning intentional from accidental action (Woodward, 1999). Research also suggests that by 9 months of age infants can understand action in terms of future goals and the efficient means to achieve these goals (Csibra, Gergely, Biró, Koós, & Brockbank, 1999), with more recent evidence suggesting this skill is evident by 6 months (Kamewrai, Kato, Kanda, Ishiguro, & Hiraki, 2005). These studies also suggest that infants do not require the presentation of the end-state of an action in order to attribute a goal to an action. Other work suggests that infants of 9 months focus on the goals of an action over other components, such as the direction of the movement (Woodward, 2003).

One important issue is the reason for why younger infants fail to detect intentions from other forms of human action. It may well be that the number of variables that are required to be maintained in working memory produce the inability to detect goal directed action in younger ages. Literally, there is too much information to maintain and therefore the processing of additional information, in this case information pertaining to goal directions, will suffer. The directed attention model can account for this in terms of overloaded working memory capacities. For example, the directed attention model would predict that a young infant would be able to maintain information about one agent displaying a different emotional stance towards two objects, whereas two agents each displaying a separate emotional expression towards one object may be an observed social situation that is too complex for an infant to process. This is particularly that case if other components of the social situation take precedence in terms of infant attention. For example, it is more socially important to determine the locus of an observed individual's attention in relation to the self than it is to identify the goal of the observed individual. There is, however, an overall caveat that much further work is required with younger infants in order to map the developmental trajectory of discerning intentions and detecting goals.

It is also possible that infants may produce a response at this stage in determining the parameters of the social situation. This may be due to the infant discerning enough information at this point in processing the situation to produce a socially correct response in the majority of settings. Potentially, the detection of goals is not required in many social situations in order for an infant to produce a valid social response.

CONCLUSIONS

We hope that this model can provide a framework in terms of information processing for understanding social-cognitive skills throughout infancy. For example, the directed attention model predicts that the addition of biological motion to more complex aspects of the social environment, such as normal and disrupted human body schema, may help facilitate detection of aspects of body schema that would not otherwise be attended to. The discrimination of possible and impossible body schema may be a likely experimental outcome, which cannot be discriminated by infants using static stimuli.

One caveat of the directed attention model is that this is a purely perceptual account of how infants successfully process social information. The infant's role in this model is entirely passive. In the real world, infants are highly interactive in their initiation of, and involvement in, social interactions. This will of course change the order of the cognitive sequence in the model. However, the individual components of detecting others and determining their direction of attention will likely not change.

The directed attention model also has implications for general learning mechanisms throughout infancy. For example, learning to determine the referent of a novel word is an intrinsically social act, as is learning to speak (see Baldwin & Moses, 2001). Application of the directed attention model to these social situations may predict the success of a given infant at these tasks due to the dynamics of the specific social situation.

This is the first attempt to produce a model integrating social capacities in infancy with known cognitive skills. To the extent that use of this interpretative framework may generate new hypotheses, it is hoped that this simple model proves a useful tool in future research in early social cognition.

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