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Is there a 'social brain'? Lessons from eye-gaze following, joint attention, and autism

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The aim of this volume is to explore what it means to understand other minds. Drawing on philosophical, developmental, and psychological perspectives, the chapters in this book address a myriad of issues including how an understanding of minds develops, its significance for social interaction, and its relation to other social and cognitive achievements. Our chapter brings yet another perspective to bear on these issues. Taking a neuroscientific approach, our discussion centers on how understanding other minds – a central aspect of social-information processing – is represented in the brain.

Currently in the literature there are two very different models of how the brain is organized for processing social information. One model, advocated by evolutionary psychologists, poses the existence of a 'social brain'. On this view, the human mind has evolved a set of domain-specific solutions to particular problems. As a consequence, there exists a set of mental systems for perceiving and reasoning about social stimuli, which act independently from the mental systems involved in perceiving and reasoning about non-social things. It is the content of the information – its social nature – that determines the dichotomy, rather than the structure of the problem (Cosmides & Tooby, 1992). These social modules are thought to be unique in their input (i.e., the information they process) as well as in their mechanism (i.e., the rules that govern their processing). Finally, their content-specificity is ostensibly caused by phylogenetic evolution rather than by familiarity, expertise, or ontogenetic development. In its neuroscientific strand, the

view posits the existence of dedicated brain areas for the processing of social information (Duchaine, Cosmides, & Tooby, 2001; Stone, 2002).

A different model, with origins in information-processing research, views the mind as a set of subsystems, each of which processes a collection of basic computations. Although the model allows for the existence of domain-specific processes and algorithms, this is not its defining feature. Rather, what dictates which brain areas become engaged are the computational operations necessary to solve the problem. For example, tasks requiring the suppression of prepotent stimuli in favor of internally generated responses tend to activate a common network of brain regions. Domain specificity may exist in the sense that motor suppression and verbal suppression may engage neighboring brain areas. However, this is not the defining feature; rather it is the specific computations performed by particular brain areas. Thus, some areas will perform suppression of prepotent representations, others will be engaged in the perception of effort, and still others will maintain representations in a mental buffer (Fernandez-Duque & Johnson, 2002). Most cognitive neuroscience research in attention, memory, imagery, and executive functions has followed this information-processing approach (Posner & Raichle, 1994).

Tasks of social relevance often engage the same network of brain areas. At first glance, this appears consistent with the idea of a 'social brain'. However, those brain areas are sometimes driven by non-social tasks too, which contradicts the 'social brain' argument. A main goal of this chapter is to put forward a synthesis that accommodates these disparate results. In agreement with information-processing models, we argue that there is no 'social brain' but rather isolable subsystems that perform basic computations. But how does this explain that social tasks tend to activate the same network of brain areas? We argue that the recruitment of similar areas by social stimuli happens because social stimuli disproportionately tap onto certain basic

computations, such as those related to affective processes. Importantly, this correlation between social stimuli and basic computations is not perfect, leaving room for non-social stimuli to engage those same brain areas, and also allowing social stimuli not to engage those areas on occasion. The absence of a perfect correlation between social stimuli and basic computational operations also makes the distinction between these two levels useful and theoretically important, rather than a mere re-description of the same phenomena.

As evidence for our main thesis, we focus on one social skill in particular – namely, the ability to detect and follow eye gaze. We review behavioral and neurological findings on eye-gaze following, and discuss its relation to other perceptual skills of social importance, such as facial emotion recognition and face identification (in depth reviews of these other skills already exist in the literature: for facial emotion recognition see Blair, 2003; Calder, Lawrence, & Young, 2001; for face identification see Kanwisher, 2000). Next, we discuss whether eye-gaze following is related to mental state attributions and joint attention. We end with a discussion of how the impairment of these abilities in autism may both shed light on their typical development and provide answers to how the brain is organized in its processing of social information.

Eye-Gaze Perception: Behavioral Evidence

Both in humans and other primates, the ability to follow the direction of gaze is of great importance for social interaction. Primates such as chimpanzees and macaques spontaneously follow the eye gaze of con-specifics, and direction of gaze conveys social dominance (Tomasello, Call, & Hare, 1998). Humans automatically cue their attention in the direction of gaze: 3-month-old infants can follow perceived gaze (Hood, Willen, & Driver, 1998), and even newborns can discriminate between direct and averted gaze, thus suggesting a strong genetic determinism with little environmental variability (Farroni, Csibra, Simion, & Johnson, 2002).

What is less clear is whether and to what extent these processes depend on mental state attributions. In non-human primates, eye-gaze following appears to be a bottom-up, non-mentalistic process (Povinelli, Bering, & Giambrone, 2000). In human adults, mental state inferences may not be necessary, even if mental attributions often co-exist with gaze following. This counterintuitive fact is well known to any basketball player who has found herself following the adversary's gaze despite knowing his intention to deceive. In experimental paradigms, subjects automatically follow the direction of the eyes even when eye gaze predicts that the target will occur in the opposite location (Driver, Davis, Ricciardelli, Kidd, Maxwell, & Baron-Cohen, 1999; Langton & Bruce, 1999). These findings, together with the early development of eye-gaze cueing in infancy, suggest a rigid, non-mentalistic system of gaze following that is driven bottom-up by the physical properties of the stimulus, such as the relation of the dark iris to the white sclera (Anstis, Mayhew, & Morley, 1969; Ricciardelli, Baylis, & Driver, 2000) and possibly also by the orientation of the head (Langton, Watt, & Bruce, 2000).

Eye-Gaze Perception: Neurological Evidence

The system for eye-gaze detection is ideal for exploring neural mechanisms of relevance to social interactions, even if in itself, eye-gaze detection is an elementary part of social behavior. For one, eye-gaze perception can be explored in non-human primates using methods such as lesions and single neuron recordings, yielding highly specific, localized information on the brain areas involved. Second, since eye-gaze perception is relatively independent from language, it is less problematic to make generalizations across species. Finally, since eye-gaze detection is driven by external stimuli, it is possible to systematically manipulate the system.

The first question to address is whether there is an isolable neural system for eye-gaze detection in its most rudimentary form. An affirmative answer would require a direct mapping of

function to brain region. Such direct mapping is admittedly a philosophically contentious issue, which includes the difficulty of conceptually defining 'function'. Nevertheless, over the last two decades, neuroscience has provided several good examples of direct mapping. Here we briefly mention two of them, before describing the eye-gaze system.

The first example is a region of the posterior temporal lobe, area MT, which has been implicated as a direct neural correlate of perceived visual movement. Area MT is activated by the aware perception of motion (Tootell, Reppas, Dale, Look, et al., 1996), its neurons respond selectively to the direction and velocity of movement, and their electrical stimulation biases the behavioral response to moving stimuli (Salzman, Murasugi, Britten, & Newsome, 1992). All these factors suggest that area MT is a specialized subsystem that computes direction and velocity of motion. The second example is the face fusiform area (FFA), an area of the ventral temporo-occipital cortex that responds selectively to faces. Subjective experience of faces activates face fusiform area even in the absence of sensory stimuli, as in the case of visual imagery (O'Craven & Kanwisher, 2000). Lesion to this area leads to impaired recognition of facial identity (Damasio, Damasio, & Van Hoesen, 1982). Thus, it appears that face fusiform area encodes structural aspects of faces, or possibly, other familiar stimuli that are decoded globally. Both area MT and FFA are specialized subsystems, but this does not mean that they are informationally encapsulated. In fact, attending to movement increases MT activation, and attention to face processing increases FFA activation (Hoffman & Haxby, 2000; O'Craven, Rosen, Kwong, Treisman, & Savoy, 1997).

Along the same lines, several studies have pointed to an area of the posterior part of superior temporal sulcus (STS) as critical for the encoding of eye gaze. In neuroimaging studies, this area is activated by faces changing the direction of gaze, and even by static displays of faces

with averted eyes (for a review, see Allison, Puce, & McCarthy, 2000). Furthermore, when the

task requires that subjects pay attention to eye gaze, the activity of STS is increased, while the

activation of FFA, the area that encodes the structural aspect of faces, remains invariant (as

expected, paying attention to face identity leads to the opposite pattern) (Hoffman & Haxby,

2000). Single neuron recording studies in monkeys reveal some neurons in the anterior part of

STS that respond specifically to gaze direction (Perrett, Hietanen, Oram, & Benson, 1992), and

gaze perception is disrupted by lesions to this area (Campbell, Heywood, Cowey, Regard, &

Landis, 1990). Finally, STS has functional connectivity with regions important for shifting

visuospatial attention to the periphery, such as the intraparietal sulcus, thus being an integral part

of the neural circuit for eye-gaze following (George, Driver, & Dolan, 2001).

The Relation of Eye-Gaze Perception to Other Aspects of Facial Information Processing:

Behavioral and Electrophysiological Evidence

Even though eye-gaze perception depends critically on the STS, the impact of eye gaze

on behavior is modulated by other factors. For example, whether attention is sustained in the

direction of gaze depends on the facial emotion. When the person whose eyes serve as a cue

looks happy, attention is sustained, but when the person looks angry, attention is relocated

somewhere else (Fenske, Frischen, & Tipper, 2004). Thus, faces expressing emotion modulate

gaze-evoked shifts of attention. Fearful faces are more effective at cueing attention than neutral

faces, at least in subjects who are anxiety-prone (Mathews, Fox, Yiend, & Calder, 2003). Direct

gaze in primates indicates social dominance and is part of the threat display, while in humans

direct gaze may indicate intimacy or aggression, depending on the accompanying facial emotion.

Faces with direct gaze are easier to identify than faces with averted gaze, suggesting that gaze

also interacts with facial recognition (Macrae, Hood, Milne, Rowe, & Mason, 2002).

The interactions among gaze, facial emotion, and facial identity also extend to their neural substrates. Thus, activation of the amygdala, a region involved in emotion recognition, is modulated by the direction of gaze. When faces with neutral expression are displayed, direct gaze leads to stronger activation of face fusiform area than averted gaze, and also increases the functional connectivity between amygdala and face fusiform area (George et al., 2001). A likely interpretation is that the emotional valence conveyed by a direct gaze gets encoded in the amygdala, which in turn modulates face fusiform area, via its feedback projections, to improve facial identity recognition. The amygdala also appears to be an integral part of the system for eye-gaze detection, as it is activated by eye gaze and its lesion impairs gaze perception (Kawashima, Sugiura, Kato, Nakamura, et al., 1999; Young, Aggleton, Hellawell, Johnson, et al.,1995).

Amygdala and STS have bilateral anatomical projections, and both areas send projections directly to the orbitofrontal cortex (OFC), an area critical for emotion regulation (Rolls, 1999). Interestingly, the medial part of OFC is activated disproportionately by attractive faces, and such activation is further increased when the attractive face is smiling (O'Doherty, Winston, Critchley, Perret, Burt, & Dolan, 2003). Lateral parts of the OFC are activated by facial expressions of anger (Blair, 2003). However, it would be a mistake to conclude that OFC is specialized for the processing of such social stimuli. OFC participates in the encoding of rewards and punishments even when they lack a social connotation (O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001). The role of OFC appears to be a more general modulation of stimulus-reward associations, of which facial emotions and direct gaze may be special cases. For example, in non-social tasks OFC lesions cause impairments in reversal learning, leading subjects to perseverate on a response long after it stops being rewarded (Dias, Robbins, &

Roberts, 1996; Fellows & Farah, 2003; Hornak, O'Doherty, Bramham, Rolls, Morris, Bullock, &

Polkey, 2004). These findings are a good example of how a brain area can be recruited by social

stimuli even if the area also participates in other, non-social processes.

Eye-Gaze Processing: Social Module or Information-Processing?

      The behavioral, functional, and anatomical results described above reveal a network of

brain structures, including area MT, FFA, STS, amygdala, and OFC, which act in concert to

compute many aspects of facial information that are important for social interactions. Much like

the findings from other cognitive systems, these results reveal a division of labor, with each area

performing a computation that is smaller than the task as a whole. At the same time, each

subsystem is heavily modulated by the others, and by general resources such as the allocation of

attention, thus arguing against any type of strong modularity.

      The available evidence also argues against a brain area – or even a network of areas –

dedicated to the exclusive processing of social stimuli. For example, area MT responds to

biological motion, but it also responds to random dot movement (O'Craven et al., 1997; Salzman

et al., 1992). STS is sensitive to eye gaze, but it is also sensitive to aspects of language (Martin,

2003), semantic knowledge (Chao, Haxby, & Martin, 1999), visuo-spatial attention, and target

detection (Corbetta & Shulman, 2002). The amygdala is important for eye-gaze detection and the

recognition of facial expressions of fear, but it also processes many other aspects of fear, for

example, Pavlovian classical conditioning, and response to aversive tastes and odors (Büchel &

Dolan, 2000; Davis & Whalen, 2001). Orbito-frontal cortex may be important for recognizing

certain facial emotions, but it is also critical for modulating non-social stimulus-reward

associations, such as the relation between key press and food. Finally, although parts of the

fusiform gyrus are particularly sensitive to faces, which are a type of social stimuli, these same

brain areas are also sensitive to non-social stimuli that are globally encoded, such as expert

recognition of cars or birds (Gauthier & Nelson, 2001, but see Farah, Rabinowitz, Quinn, & Liu,

2000, Grill-Spector, Knouf, & Kanwisher, 2004).

In sum, there is a network of brain regions disproportionately engaged by social stimuli

such as faces. But those areas are also engaged in basic computations of no social relevance.

Thus, their engagement by social stimuli is insufficient proof for the existence of a 'social brain'.

Rather, it suggests that social stimuli often carry particular properties – valence, reward value,

spatial arrangement of its features—that disproportionately tap certain basic operations.

Eye-Gaze Perception: A Window into Mental State Attribution?

There is no doubt that encoding and following eye gaze are important social skills for

both human and non-human primates. Nor is there any doubt that normal human adults often

make mental state attributions about the eye-gaze patterns they detect: When an agent directs his

eyes to an object, adults infer that he is seeing the object (i.e., creating a mental representation

that can be used for guiding future behavior, enriching knowledge, and so forth). For normal

human adults, the behavioral description (eye gaze) and its mentalistic re-description (seeing)

almost always go hand in hand. Moreover, during development, the co-variance between the

mentalistic and non-mentalistic levels (i.e., between the 'looking at' and the alignment of gaze

direction and attended object) may play a role in fostering the emergence of mental state

attribution. That is, such co-variance may help to bootstrap mental state attribution in typically

developing human infants who are experience-ready. But there is no principled reason why this

should be true in other populations. Newborns, monkeys, and individuals with autism may detect

and follow eye gaze without taking the extra step of attributing mental states to such behaviors

(Povinelli et al., 2000).

On the whole, knowing about eye-gaze detection tells us little about whether mental state attributions are being made. Similarly, identifying the brain areas involved in eye-gaze detection tells us little about which areas are critical, or even necessary, for the attribution of mental states. Just because behavior and mental states tend to co-occur does not mean that the same brain areas involved in detecting the behavior would also be involved in the attribution of mental states to that behavior. In fact, eye-gaze following implicates homologous brain areas in humans and in species incapable of mental state attribution, such as macaque monkeys. This homology is sometimes interpreted as evidence that those brain areas, in the course of phylogenetic evolution, gave rise to mentalizing abilities (Frith, 2001). However, this is not necessarily the case. An alternative view is that the across-species similarity in the brain mechanisms of eye-gaze detection is in fact evidence against a central role of these structures in mental state attribution. In other words, if both humans and macaques recruit homologous brain areas to detect eye gaze, but only humans make mental state attributions, it is reasonable to conclude that mental state attribution depends on some other brain structures. To put it bluntly, computing the direction of gaze is not the same as using the direction of gaze to infer another's intention, nor need it depend on the same brain structures.

Development: From Reflexive Eye Cueing to Joint Attention

So far, we have been describing the rudimentary system of eye-gaze detection, but in typically developing humans this rudimentary system becomes part of a more sophisticated system rather quickly in development. At the age of 9 months, infants start using direction of gaze in a more flexible manner that takes into account people's communicative intentions, a skill that forms part of what has been labeled 'joint attention'. Joint attention is the ability to coordinate attention between interactive social partners with respect to objects or events. It

reveals an understanding by infants that adults are intentional agents; that is, that adults

voluntarily attend to objects and that their attention can be shared, directed, and followed.

Besides responding to another's gaze shift, joint attention includes behaviors such as proto-

declarative pointing (i.e., pointing to refer to an object, as opposed to pointing to request an

object), imitative learning (i.e., acting on objects the way that adults are acting on them), and

social referencing (i.e., infants' reference to adults for information about the approachability,

desirability, and other features of objects) (Tomasello & Rakoczy, 2003). All four of these skills

– the flexible use of eye-gaze following, proto-declarative pointing, imitative learning, and social

referencing-- are correlated, develop in synchrony between the ages of 9 and 24 months, and

show little influence from environmental variables. Across these behaviors, there seems to be the

expression of a single, underlying skill – the understanding of persons as intentional agents--

which is almost completely absent in other primates (Povinelli et al., 2000; Tomasello &

Rakoczy, 2003). As such, it may be the single, most important developmental milestone in the

understanding of other minds. At the same time, the features that make it so remarkable, namely

its early emergence in development and its exclusivity to humans, are the same that make it

inaccessible to most of the methods of cognitive neuroscience.[1] Although adult neuropsychology

and neuroimaging provide good approximations and hypotheses, it would be erroneous to simply

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[1] Currently, there are two non-invasive neuroimaging methods suitable for infant studies: event-related potentials (ERPs) and event-related optical signal (EROS). Other methodologies are either too invasive (e.g., positron emission tomography, PET) or require subjects to remain still for several minutes (fMRI). ERPs are recordings of electrical activity from the scalp, averaged over many trials time-locked to the stimulus onset. It has an excellent temporal resolution of 4 ms, and therefore can be used to determine the stage in information processing at which two conditions diverge. In contrast, its spatial resolution is only modest, due to the many layers of tissue that exist between the brain source and the surface of the scalp, which tend to disperse the signal. Certain methodological considerations, such as the contamination by muscle activity, require that subjects are compelled not move their eyes. In EROS an external source emits near infra-red light from the scalp surface. This light is scattered by the brain and received by a detector, also in the scalp surface. Neuronal activity modulates the optical scattering properties of the brain, and this is used to assess which brain areas are active. Unlike ERPs, EROS has not only good temporal resolution but also good spatial resolution. However, only certain regions of the brain surface are suitable to the techinque. Although it is a very recent methodology, EROS is a promising approach for studying cognitive neuroscience in human infants (Gratton, 2001).

extrapolate from these models to the case of development (Karmiloff-Smith, 1998). Therefore,

researchers have been interested in diseases of development, autism in particular, to provide a

more complete picture of how these developing abilities map onto brain structures.

Developmental Disorders: The Case of Autism

Autism is a neurodevelopmental disorder with a strong genetic component and a

heterogeneous neurological substrate. Abnormalities have been reported in the limbic system

(anterior cingulate, amygdala, hippocampus and orbitofrontal cortex), cerebellum, frontal lobes,

superior temporal gyrus, and subcortical structures including the thalamus and the basal ganglia

(Lord, Cook, Leventhal, & Amaral, 2000). This broad range of neurological abnormalities is

matched at the behavioral level by a broad phenotype that includes motor, linguistic, social, and

emotional deficits (Joseph, 1999). Individuals with autism exhibit stereotypic and repetitive

motor behavior, and their use of language is both delayed and disrupted. At its core, however,

autism is a disorder of social interaction and communication.

Poor eye-gaze following is a specific marker of autism, and one of its earliest signs,

evident in children as young as 18 months of age. Some children with autism even fail to use

gaze as a cue to locate an object (Leekam & Moore, 2001). This is especially remarkable given

that chimpanzees, who are incapable of joint attention, can nevertheless use gaze as an

instrumental cue (Povinelli & Eddy, 1997). In one study, school-aged children with autism were

tested in a naturalistic environment for their ability to use eye gaze as an orienting cue. In the

autistic group, children with high mental age performed normally, but those with low mental age

were impaired relative to developmentally delayed children matched for mental age. Autistic

children of low mental age were capable of following gaze when a target was observable --a skill

that emerges at 6 months of age in typically developing infants -- but were impaired when the

target was absent – a skill that normally develops at the age of 9 months and that indicates the emergence of joint attention (Leekam & Moore, 2001). Another study tested high-functioning 10-year-olds with autism in a computer-based paradigm and found normal cueing effects (Sweettenham, Condie, Campbell, Milne, & Coleman, 2003). Using a variant of the Posner cueing task, each trial displayed a face with averted gaze and a peripheral target in close temporal sequence. Although the direction of gaze did not reliably predicted the location of the future target, responses were fastest when gaze was directed to the target location. This effect was present when the target appeared just 100 ms after the cue, consistent with an automatic cueing of attention. Thus, consistent with the findings from Leekam and Moore (2001), reflexive eye cueing appears to be spared in high-functioning children with autism. Taken together, these two studies suggest that eye-gaze cueing deficits in autism vary according to the severity of impairment in general intelligence.

In contrast, joint attention deficits in autism occur independently of general intelligence, and are an early marker of the disease. Children with autism show deviant patterns of reciprocal gaze behavior with their caregivers as well as deficits in the triadic coordination among themselves, adult, and object (Charman, 2003). Interestingly, joint attention in 3- and 4-year-old children with autism is positively correlated with orbitofrontal function, as measured by tasks that engage this region in normal subjects (Dawson et al., 2002).[2] Orbitofrontal cortex is necessary for adding flexibility to stimulus-reward associations (Fellows & Farah, 2003; Rolls, 1999). An inability to assign stimulus-reward associations and flexibly modify them could be detrimental to the development of joint attention, as joint attention depends on social rewards,

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[2] Ventro-medial prefrontal function was measured with tasks that are disrupted by lesions to the orbitofrontal cortex in monkeys and human adults. **These are tasks that require a modification of behavioral response when a particular response is no longer rewarded, such as the delayed nomatching to sample with brief delay task and object discrimination reversal task.**

such as smiles, that are more variable than non-social rewards. Consistent with this hypothesis,

autistic infants and toddlers prefer highly contingent, non-variable feedback, while typically

developing children instead prefer variable, imperfect feedback (Gergely & Watson, 1999). The

contingency hypothesis illustrates the main problem of arguing for a module devoted exclusively

to social stimuli. Even if certain brain regions do process social stimuli preferentially, it does not

follow that such preferential processing is due to the 'social' nature of the stimuli. In the

aforementioned example, the driving force is the variability of the stimulus-reward association,

which is typical of social stimuli but can present in non-social stimuli.

        Individuals with autism also show abnormalities in the processing of facial and emotional

stimuli. ERPs (event-related potentials) reveal that children with autism are impaired in the

discrimination of novel versus familiar faces, despite their normal discrimination of novel versus

familiar objects. In adults with autism, faces trigger reduced activity in fusiform area, amygdala,

and superior temporal sulcus, among other areas (Critchley, Daly, Bullmore, & Williams, 2000).

One possible interpretation of these data is that they provide evidence for a social-perception

module, whose impairment in autism accounts for the social deficits exhibited by this group.

Although this analysis captures much of what is wrong in autism, it makes the same mistake

previously described in our analysis of stimulus-reward associations. Just because social stimuli

such as faces happen to activate face fusiform area, it does not follow that faces activate this area

because they are stimuli of social relevance. Non-social stimuli such as cars and birds can

similarly activate this region, provided that observers are experts in recognizing those objects

and encode them globally. The critical factor, therefore, is not the social nature of the stimulus

but its holistic encoding. In fact, preliminary evidence suggests that the face fusiform area of

individuals with autism is activated when they are engaged in holistic encoding of non-social

stimuli. For example, a child with autism who had great expertise in Digimon cartoon characters – which presumably are non-social stimuli – showed face fusiform activation to Digimon figures but not to human faces (Grelotti, Klin, Gauthier, Skudlarski, et al., 2004). Interestingly, amygdala also activated in this child, suggesting that such figures were emotionally laden, despite their lack of social relevance.

Of course, this is not to say that difficulties in face perception, emotion recognition, and gaze following do not have consequences for mentalizing. On the contrary, such deficits may put children with autism at a severe disadvantage in their development of mental state understanding. Relative to typically developing children, children with autism have difficulties using the eyes as cues for attributing mental states (Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001) and in using faces to judge the approachability and trustworthiness of people (Adolphs, Sears, & Piven, 2001). There is also evidence that children with autism have difficulties understanding gaze in mentalistic terms. In one task, children were shown a cartoon face and asked whether the character was looking straight ahead at them or was looking away. Children with autism were capable of correctly discriminating between these two displays. However, when asked to select which of four items (e.g., types of candy) the character liked best, the same children were unable to use eye gaze to infer that the best-liked item was the one the character was staring at (Baron-Cohen, 1995).

So, is autism best characterized as a deficit in a social module or as a general disorder of basic processes that apply to both social and non-social domains? Individuals with autism have deficits in joint attention and mental state attributions, but they also have motor deficits, visual attention deficits, and deficits in feedback processing, set switching, executive processing, and other non-social abilities (Joseph, 1999). Thus, although autism may present first and foremost as

a problem of social cognition, it also manifests itself in non-social problems. This dual deficit

poses a challenge to both the social-module view (why should there be non-social deficits?) and

the domain-general view (why should the deficit be mostly social?). Our proposal is that the

solution to this paradox lies not in the brain itself but in the external stimuli that the brain

processes. More specifically, we argue that attributes of social stimuli may correlate with basic

information-processing computations. According to our framework, a deficit in the basic

computation would affect primarily, but not exclusively, the processing of social information.

We have already discussed the examples of variable stimulus-reward associations and holistic

visual encoding. In both cases, there is a correlation between the type of stimulus (social/non-

social) and a computational feature (variable/non-variable reward; holistic/feature-based

encoding). We are not claiming that these two basic computations account for all deficits in

autism; rather, we use these examples to illustrate the larger point that general computational

deficits may account for what appear to be domain-specific deficits.

    Stimulus category (social/non-social) may correlate with other basic computations, such

as those involved in affective processing. Since social stimuli carry more affective valence than

non-social stimuli they should disproportionately tap limbic structures such as the amygdala and

the orbitofrontal cortex. Limbic areas are activated by affective stimuli such as faces. These brain

areas send feedback projections to regions of the temporal lobe including the fusiform gyrus.

During normal development, this affective loop is likely to play a role in modulating the

plasticity of the fusiform gyrus, which with experience becomes a dedicated system for face

recognition (i.e., the face fusiform area). To put it in psychological terms, faces are attractive

stimuli which capture the child's attention, thus becoming the focus of preferred processing, and

with the passage of time, a stimulus the child is expert with. But for children with autism, faces

do not seem to carry their appropriate valence, and thus these children seem uninterested in

faces. Within a social-module framework, there is little one could do to rectify this problem.

Within an information-processing framework, however, it should be possible to pair facial

stimuli with non-social rewards that are valued by the autistic child, and in this way engage the

affective loop. Through extensive training in such a paradigm, it might be possible for children

with autism to achieve the type of expertise with facial stimuli that typically developing children

gain naturally (Carver & Dawson, 2002).

Also related to the affective dimension, type of stimulus (social/non-social) may correlate

with orienting effectiveness. For example, while the orienting deficit in autism is most severe for

social stimuli, such as faces or being called by name, individuals with autism are also impaired in

their orienting to non-social stimuli, such as a jack-in-the-box (Dawson, Meltzoff, Osterling,

Rinaldi, & Brown, 1998). Interestingly, deficits in joint attention correlate with deficits in

orienting toward social stimuli but not with non-social orienting. This result is consistent with

the idea raised earlier that the co-variance of mental and non-mental levels (orienting to a

location, find a social stimuli at that location) may foster the mental state attribution process.

Conclusions

The re-description of social information into basic information-processing computations

may prove to be a powerful tool. We mention examples in the context of autism, but it is easy to

see how the logic can generalize to typical development. Importantly, such re-description

provides the system for processing social stimuli with a flexibility that is central to social

interactions, and that a social-module framework cannot easily account for. Imagine that

somebody stares at you with an angry face. Depending on the context, you might feel amused

(the person is an actor you are watching in a play), frightened (you are in a shady part of town),

or disgusted (the person is the leader of the world superpower justifying his next imperialistic

adventure). In other words, it is easy to imagine that one and the same stimulus will be processed

very differently depending on the context (Lange, Williams, Young, Bullmore, et al., 2003).

Such context effects cannot be explained by models posing a strict separation of social and non-

social information. In contrast, an information-processing account can easily accommodate for

these contextual effects, as it assumes that general cognitive abilities can influence the

processing of information. Re-conceptualizing the social brain in terms of basic information

processes also allows researchers to ask 'how' – in computational terms – social information is

processed. Finally, it entrenches social neuroscience within the cognitive neuroscience tradition

that has been so fruitful over the last two decades. Just as the brain does not make a strict

separation between social and cognitive information, neither should brain researchers.

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