

VIEWPOINT

Developing a social brain

Mark H Johnson (mark.johnson@bbk.ac.uk)

Birkbeck, University of London, London, WC1E 7HX, U.K.

Keywords

Cortex, Faces, Infancy, Social Cognition

Correspondence

Mark H. Johnson, Centre for Brain and Cognitive Development, School of Psychology, Birkbeck, University of London, Malet Street, London, WC1E 7HX.

Tel.: +44 207 631 6226

Fax: +44 207 631 6587

Email: mark.johnson@bbk.ac.uk

Received

12 May 2006; revised 12 May 2006; accepted 16 May 2006

DOI:10.1111/j.1651-2227.2006.00037.x

**Abstract**

A new account of human postnatal functional brain development, interactive specialization (IS), is introduced and applied to one important domain of human development: the social brain. Behavioural, ERP and fMRI evidence from newborns, infants and children in face processing tasks is briefly reviewed, and is shown to be consistent with predictions from the IS account.

Conclusion: It is suggested that this new view of functional brain development can also be applied to other domains of typical and atypical human development.

One of the fundamental questions in neurobiology concerns how different regions of the cortex develop their specificity. This question is particularly salient in humans where regions of cortex support 'higher cognitive functions' not seen in most other mammals, and where development is comparatively delayed and continues well in to the postnatal years. This issue is particularly acute because it underpins all cognitive neuroscience studies of adults in which cognitive functions are localized to areas of cortex, and because it is of potential relevance to future educational and clinical strategies.

One major example of the specialization of adult human cortex is its processing of social stimuli. While most adults have regions of the brain specialized for processing and integrating sensory information about the appearance, behaviour and intentions of other humans, how these specializations emerge during development remains largely unknown. Indeed, the ontogeny of the social brain is an example of the broader issue of postnatal functional brain development in humans. Relating evidence on the neuroanatomical development of the brain to the remarkable changes in motor, perceptual and cognitive abilities during the first decade or so of a human life presents a considerable challenge. Three distinct, but not necessarily incompatible, approaches to this issue have been identified (1,2): (a) A maturational perspective, (b) a skill-learning viewpoint and (c) interactive specialization (IS).

Much of the research to date attempting to relate brain to behavioural development in humans has been from a *mat-*

urational viewpoint in which the 'maturation' of particular regions of the brain, usually regions of cerebral cortex, is related to newly emerging sensory, motor and cognitive functions. Evidence concerning the differential neuroanatomical development of brain regions can be used to determine an age when a particular region is likely to become functional. Success in a new behavioural task at this age is then attributed to the maturation of a new brain region. With regard to the social brain network, different cortical modules relevant to social perception and cognition would mature at different postnatal ages.

A contrasting view of the developing social brain comes from the 'skill learning' perspective, in which the changes in neural activity seen during functional brain development in infants and children as they acquire new perceptual or motor abilities are proposed to be similar to those involved in complex perceptual and motor skill acquisition in adults. For example, Gauthier and colleagues have shown that extensive training of adults with artificial objects (called 'greebles') eventually results in activation of a cortical region previously associated with face processing, the 'fusiform face area' (3). This suggests that the region is normally activated by faces in adults, not because it is prespecified for faces, but due to our extensive expertise with that class of stimulus. This may also provide an account of the development of face processing skills in children (4). From this perspective, the adult 'social brain' results from us becoming experts in perceiving and processing social stimuli during development.



Figure 1 An infant wearing the Geodesic Sensor Net EEG system. This high-density array of sensors allows investigation of the spatial and temporal dynamics of infant brain activity. Photo: Sarah Fox

The third perspective, ‘interactive specialization’ (IS) is based on the evidence that some cortical regions begin with poorly defined functions, and are consequently partially activated in a wide range of different contexts and tasks. During development, activity-dependent interactions between regions tune the functions of cortical regions such that their activity becomes restricted to a narrower set of circumstances (e.g. a region originally activated by a wide variety of visual objects may come to confine its response activity to upright human faces) (1,2). According to this view, during postnatal development, changes in the response properties of cortical regions occur as they interact and compete with each other to acquire their role in new computational abilities. The onset of new behavioural competencies during infancy will therefore be associated with changes in activity over several regions, and not just by the onset of activity in one or more additional region(s). In terms of the developing social brain, the IS view predicts initial biases that are sufficient to kick-start a process of cortical specialization for the perception and processing of social stimuli. A consequence of becoming increasingly specialized for social stimuli is increasing focal patterns of cortical activation during development.

When considering different accounts of the origins of the social brain network, it is useful to begin at birth, and with a relatively simple facet of social brain function, the detection of faces. A number of studies have shown that newborn human infants preferentially look toward simple face-like patterns (e.g. Ref. (5)).

A recent review of many studies on face-related preferences in newborn infants revealed that similar stimuli may attract newborns as are found to elicit activation in a sub-cortical route for face processing in adults (6). This stimulus could be as simple as dark blobs corresponding to the gen-

eral location of the eyes and mouth, or a bounded surface with more dark elements in the upper half. In either case, the representation is probably close to the minimum sufficient to elicit orienting to faces within the natural environment of the newborn, and given the constraints of the newborn visual system.

One purpose of this early bias to fixate on faces may be to elicit bonding from adult caregivers. However, an equally important purpose is to bias the visual input to plastic cortical circuits. This biased sampling of the visual environment over the first weeks of life may ensure the appropriate specialization of later developing cortical circuitry (7), and thus provide a developmental foundation for the emerging social brain network (6).

While the current evidence on newborn face preferences is difficult to reconcile with a strictly skill learning view of functional brain development, it is consistent with either the maturational or IS approaches. However, these two views make different predictions about development over the ensuing months and years of life. According to the maturational approach, development beyond the newborn involves the addition of more complex modules that mature at later ages. In contrast, the IS view predicts increasing specialization (tuning) and more focal localization of cortical processing as a result of further development.

There is a growing body of evidence on the neural basis of face perception over the early months and years of life. One issue that has been addressed is how specific (finely tuned) cortical face processing is at different points in development. In particular, attention has focused on the ‘N170’, an event-related potential component that has been strongly associated with face processing in a number of studies on adults (see (8) for review). An important aspect of the N170 in adults is that it has a highly selective response. For example, we observed that the N170 showed a different response to human upright faces than to very closely related stimuli, such as inverted human faces and upright monkey faces (9). Thus, the specificity of response of the N170 can be taken as an index of the degree of specialization of cortical processing for human upright faces. With this in mind, a number of studies have investigated the specificity or otherwise of the N170 in infants (see Figure 1). In studying the response properties of this brain potential at 3, 6 and 12 months of age, we have discovered that (a) the component is present from at least 3 months of age (although its development continues into middle childhood), (b) the component becomes more specifically tuned to human upright faces with increasing age and (c) there is stronger evidence for cerebral lateralisation of the component at older ages. Thus, study of this component is consistent with the idea of increased specialization and localization resulting from postnatal development.

As noted above, according to the IS approach, a consequence of increasingly finely tuned cortical processing is more focal patterns of cortical activation with increasing age. Direct evidence for increased localization comes from a recent fMRI study of the neural basis of face processing in children compared to adults (10). In this study, children

activated a larger extent of cortex around face-sensitive areas than did adults during a face-matching task.

Thus, with regard to face perception, the available evidence from newborns allows us to rule out the skill learning hypothesis, while the evidence on the neurodevelopment of face processing over the first months and years of life is consistent with the kinds of dynamic changes in processing expected from the IS, and not the maturational approach. Evidence from this initial case study of face processing is therefore consistent with the view that a variety of constraints operate on a process of emerging specialization such that cortical regions specialized for face processing is the inevitable result of the typical developmental trajectory.

Current work is going beyond the simple detection of faces to the investigation of the perception and processing of eye gaze and human action, and is investigating the atypical development of the social brain observed in autism. In addition, the IS approach is being applied to other domains of human development such as object processing (11). A cognitive neuroscience approach to development over the early years may shed light on the combinations of factors that contribute to individual differences, and thus eventually lead to improved educational provision and clinical remediation strategies.

ACKNOWLEDGMENTS

I acknowledge financial support from the Medical Research Council (U.K.) (grant G9715587) and Birkbeck College.

References

1. Johnson MH. Functional brain development in humans. *Nature Rev Neurosci* 2001; 2: 475–83.
2. Johnson MH. *Developmental cognitive neuroscience*. 2nd ed. Oxford: Blackwell, 2005.
3. Gauthier I, Tarr MJ, Moylan J, Skudlarski P, Gore JC, Anderson AW. The fusiform 'face area' is part of a network that processes faces at the individual level. *J Cogn Neurosci* 2000; 12: 495–504.
4. Gauthier I, Nelson CA. The development of face expertise. *Curr Opin Neurobiol* 2001; 11: 219–24.
5. Johnson MH, Dziurawiec S, Ellis H, Morton J. Newborns' preferential tracking of face-like stimuli and its subsequent decline. *Cognition* 1991; 40: 1–19.
6. Johnson MH. Subcortical face processing. *Nature Rev Neurosci* 2005; 6: 766–774.
7. Morton J, Johnson MH. CONSPEC and CONLERN: a two-process theory of infant face recognition. *Psychol Rev* 1991; 98: 164–81.
8. de Haan M, Johnson MH, Halit H. Development of face-sensitive event-related potential components during infancy. *Int J Psychophys* 2003; 51: 45–58.
9. de Haan M, Pascalis O, Johnson MH. Specialization of neural mechanisms underlying face recognition in human infants. *J Cogn Neurosci* 2000; 14: 199–209.
10. Passarotti AM, Paul BM, Bussiere JR, Buxton RB, Wong EC, Stiles J. The development of face and location processing: an fMRI study. *Dev Sci* 2003; 6: 100–17.
11. Csibra G, Davis G, Spratling MW, Johnson MH. Gamma oscillations and object processing in the infant brain. *Science* 2000; 290: 1582–5.