ENCYCLOPEDIA on Early Childhood Development

BRAIN

Attention and Early Brain Development

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September 2020, Éd. rév.

Introduction

Attention serves several functions related to information processing. It selects certain events or objects in the environment to focus on and maintains focus on the object of interest while information provided by that object is processed. Additionally, while attention is focused on one object, shifts in attention to distractors are inhibited. These aspects of attention show major developmental change throughout infancy.

Subject

In infants, attention is thought to change with age concurrently with changes in brain function. Models of attention in early development are based upon behavioural findings in human infants, integrated with findings on changes in brain function of non-human and human adults, or clinical populations.[1-7] Many of these models are influenced by Schiller's research[8] on eye movement systems in non-human primates. In infants from birth to two months of age, it is proposed that eye movements are primarily driven by a "reflexive system" largely under the influence of primitive brain areas located beneath the cerebral cortex (i.e., subcortical). Thus, eye movements and visual attention are generally reflexive in early infancy. Between three and six months of age, a voluntary orienting network becomes functionally mature. This network includes areas within the parietal and temporal cortices and the frontal eye fields and is involved in the ability to voluntarily shift visual attention from one stimulus to another.[9-11] From six months on, the anterior attention network (or executive attention system) becomes functional, as areas within the prefrontal cortex and the anterior cingulate cortex begin to play a significant role in maintaining visual attention while inhibiting shifts of attention to distractors.

Problems

Traditionally, infant visual attention and brain development have been measured using looking time and eye tracking measures during "marker tasks". These are behavioural tasks for which the brain areas involved have been firmly established, thus they can be used to indirectly study brain development in infants and children.[12] Instead, Richards and colleagues[13,14] suggest that integrating direct physiological measures of brain activity provides a fuller picture of the development of attention. Most of the major approaches to direct measurement of cortical activity (e.g., positron emission tomography, functional magnetic resonance imaging) cannot be used with human infant participants because of ethical and/or practical concerns. Both near infra-red spectroscopy (NIRS) and electroencephalography (EEG) can measure neural responses during cognitive tasks in pediatric populations. Moreover, source localization methods allow us to reconstruct the neural generators of the activity recorded on the scalp. We describe how these techniques can be applied to track the development of human infant brain activity.

Research Context

Infant attention is measured in the laboratory using looking time, heart rate, and the electroencephalogram (EEG).[15-18] Infant heart rate shows a sustained decrease during periods of attention, triggered by activity within the brain stem.[19] The EEG measures electrical activity that is produced in the brain with electrodes on the scalp. Event-related potentials (ERPs) are time-locked changes in EEG that are in response to a specific event or task. Source localization algorithms can be utilized to determine which brain areas are the likely sources of EEG/ERP electrical activity or NIRS blood oxygen level dependent (BOLD) response measured on the scalp.[16-18,20] This approach can provide a more direct measure of infant brain activity involved in attention.

Key Research Questions

The key research questions addressed by this line of work are what areas of the brain are involved in infant attention, whether the areas involved in attention change across the course of infant development and, whether electrophysiological measures of attention are consistent with behavioural measures of attention. Ultimately, all these questions relate to the need to learn more about brain-behaviour relations in infancy by focusing on the growing field of direct neurophysiological measures.

Recent Research Results

In infant ERP research, a component labeled Negative central (Nc) is more active following salient stimuli and likely related to attention.[15,21,22] Reynolds and Richards[16] found areas of the brain involved in the Nc component are located within the prefrontal cortex and the anterior cingulate. Remember these are areas associated with the executive attention system. The Nc component increases in amplitude with age, indicating increased attention-related activity in the prefrontal cortex during infancy.[15,23,24] This parallels increased voluntary control of attention, demonstrating the Nc component can be used to index attentional engagement in the brain.[25] Infants generally prefer novel stimuli,[26] showing increased look durations and head turns to novel faces compared to familiar faces.[27] With stimulus repetition, the Nc component shows a decrease in amplitude.[28] For example, infants habituated to one category of faces show greater Nc amplitude to novel compared to familiar faces.[29] This sensitivity to faces is linked to heart rate defined attentional states. Infants show larger Nc amplitude during heart rate defined periods of attention when viewing faces compared to objects, and they show larger Nc amplitude overall during attentive states compared to inattentive states.[24,30] Taken together, these findings show consistency between behavioural, heart rate, and neural correlates (i.e., ERP and sources) of infant attention. Recently, EEG source analysis has been applied to the investigation of different attentional mechanisms[31-33] and face[24,30] and language[34,35] processing, suggesting the importance of the technique as an imaging modality to investigate neural development.

Research Gaps

Although the application of source analysis to infant ERP data represents a major step in measuring attention-related infant brain activity, there is still much room for progress. Source analysis models for pediatric populations are becoming more precise thanks to the realistic description of the head anatomy provided by structural MRIs. Age-appropriate MRI templates necessary for accurate source analysis studies[36] are made available in the Neurodevelopmental MRI Database.[37] These templates have been successfully used to reconstruct the neural generators of both EEG and NIRS signals during attentional tasks.[16,18,31–33,38] Further application of this approach should be done for a better understanding of the developmental changes in attention. Moreover, further progress must be made in designing new procedures to simultaneously measure behavioural and neural correlates of infant attention. Until these research gaps are addressed, our knowledge of infant brain activity and brain-behaviour relations will remain constrained by methodological limitations.

Conclusions

There is a rich history of behavioural research on the development of attention in infancy. Additionally, several scientists working in the area have proposed models of infant brain development, integrating behavioural findings from infant research with research on brain development in animals and adults.[1-7] While many of the models may accurately describe the progression of infant brain development in relation to attention, at present the models remain untested because of methodological constraints. However, major progress has been made, and we now know that there is consistency between commonly used behavioural, heart rate, and electrophysiological correlates of infant attention.[15,17] We have made an initial step in identifying areas of the brain related to cognitive development by demonstrating that areas of the prefrontal cortex and the anterior cingulate are involved in infant attention.[16-18,30,31,33] Infant templates have also been developed, allowing us to move from using adult templates to interpret infant data.[37] New research can focus on specifics such as individual variability and neurodivergent populations now that we have a solid foundation in place.[39] We are confident that steady progress will continue in research on infant brain development and attention.

Implications

One of the major implications of research on infant attention relates to attention deficit hyperactivity disorder (ADHD). It is currently estimated that ADHD affects approximately 10% of school-aged children.[40] Symptoms of ADHD include poor control of attention, inattentiveness, hyperactivity, poor impulse control, and behaviour management problems. Evidence indicates that the inattentive aspect of ADHD may be related to deficits in the voluntary orienting network, whereas the hyperactive aspect of ADHD may be related to a poorly functioning executive attention system.[41,42] Children with ADHD show a delay in the development of cortical thickness[42] in the prefrontal cortex as well as altered functioning of executive attention and default mode networks.[43] These systems involve the prefrontal cortex and anterior cingulate, areas identified as sources of attention-related cortical activity in our research on infant attention.[16,17] ADHD is typically not apparent in affected children until the school years. These children may be referred to health-care professionals for problems controlling their behaviour in classroom settings. It would be ideal to have an earlier identification method for children at risk of developing ADHD. The promise of basic research on infant attention and brain development is the potential identification of atypical patterns of infant development that may predict later onset of ADHD.

References

1. Bronson GW. The growth of visual capacity: Evidence from infant scanning patterns. *Advances in Infancy Research*. 1997;11:109-142.
2. Colombo J. On the neural mechanisms underlying developmental and individual differences in visual fixation in infancy: Two hypotheses. *Developmental Review*. 1995;15(2):97-135. doi:10.1006/drev.1995.1005
3. Hood BM. Shifts of visual attention in the human infant: A neuroscientific approach. In: Rovee-Collier C, Lipsitt LP. *Advances in infancy research*. Vol 9. Norwood, N.J. : ABLEX Pub. Corp.;1995:163-216.
4. Johnson MH. Cortical maturation and the development of visual attention in early infancy. *Journal of Cognitive Neuroscience*. 1990;2(2):81-95. doi:10.1162/jocn.1990.2.2.81
5. Maurer D, Lewis TL. Overt orienting toward peripheral stimuli: Normal development and underlying mechanisms. In: Richards JE, ed. *Cognitive neuroscience of attention: A developmental perspective*. Hillsdale, NJ: Lawrence Erlbaum Press; 1998:51-102.
6. Posner MI. Orienting of attention. *Quarterly Journal of Experimental Psychology*. 1980;32(1):3-25. doi:10.1080/00335558008248231
7. Richards JE. Development of attentional systems. In: De Haan M, Johnson M, eds. *The cognitive neuroscience of development.* New York, NY: Psychology Press; 2002.
8. Schiller PH. A model for the generation of visually guided saccadic eye movements. In: Rose D, Dobson VG, eds. *Models of the visual cortex.* Chichester, NY: John Wiley; 1985:62-70.
9. Posner MI. Attention in cognitive neuroscience: an overview. In: Gazzaniga MS, ed. Cognitive neurosciences. Cambridge, MA: MIT Press; 1995:615-624.
10. Posner MI, Petersen SE. The attention system of the human brain. *Annual Review of Neuroscience*. 1990;13(1):25-42. doi:10.1146/annurev.ne.13.030190.000325
11. Petersen SE, Posner MI. The attention system of the human brain: 20 years after. *Annual Review of Neuroscience.* 2012;35(1):73-89. doi:10.1146/annurev-neuro-062111-150525
12. Richards JE. The development of visual attention and the brain. In: de Haan M, Johnson MH, eds. The cognitive neuroscience of development. New York, NY: Psychology Press; 2003:73-98.
13. Richards JE. Attention in the brain and early infancy. In: Johnson SP, ed. *Neoconstructivist: The new science of cognitive development*. New York: Oxford University Press; 2010:3-31.

14. Richards JE, Hunter SK. Testing neural models of the development of infant visual attention. *Developmental Psychobiology.* 2002;40(3):226-236. doi:10.1002/dev.10029

15. Richards JE. Attention affects the recognition of briefly presented visual stimuli in infants: An ERP study. *Developmental Science*. 2003;6(3):312-328. doi:10.1111/1467-7687.00287

16. Reynolds GD, Richards JE. Familiarization, attention, and recognition memory in infancy : an event-related potential and cortical source localization study. *Developmental Psychology.* 2005;41(4):598-615. doi:10.1037/0012-1649.41.4.598

17. Reynolds GD, Courage ML, Richards JE. Infant attention and visual preferences: converging evidence from behavior, event-related potentials, and cortical source localization. *Developmental Psychology*. 2010;46(4):886-904. doi:10.1037/a0019670

18. Reynolds GD, Richards JE. Cortical source localization of infant cognition. *Developmental Neuropsychology*. 2009;34(3):312-329. doi:10.1080/87565640902801890

19. Richards JE, Casey BJ. Development of sustained visual attention in the human infant. In: Campbell BA, Hayne H, Richardson R, eds. *Attention and information processing in infants and adults: Perspectives from human and animal research.* Hillsdale, NJLawrence Erlbaum; 1992:30-60.

20. Lloyd-Fox S, Richards JE, Blasi A, Murphy DGM, Elwell CE, Johnson MH. Coregistering functional near-infrared spectroscopy with underlying cortical areas in infants. *Neurophotonics*. 2014;1(2):025006. doi:10.1117/1.nph.1.2.025006

21. Courchesne E, Ganz L, Norcia A. Event-related brain potentials to human faces in infants. *Child Development.* 1981;52(3):804-811. doi:10.2307/1129080

22. De Haan M, Nelson CA. Recognition of the mother's face by six-month-old infants: a neurobehavioral study. *Child Development*. 1997;68(2):187-210. doi:10.1111/j.1467-8624.1997.tb01935.x

23. Webb SJ, Long JD, Nelson CA. A longitudinal investigation of visual event-related potentials in the first year of life. *Developmental Science*. 2005;8(6):605-616. doi:10.1111/j.1467-7687.2005.00452.x

24. Conte S, Richards JE, Guy MW, Xie W, Roberts JE. Face-sensitive brain responses in the first year of life. *Neuroimage*. 2020;211:116602. doi:10.1016/j.neuroimage.2020.116602

25. Courage ML, Reynolds GD, Richards JE. Infants’ attention to patterned stimuli: Developmental change from 3 to 12 months of age. *Child Development*. 2006;77(3):680-695. doi:10.1111/j.1467-8624.2006.00897.x

26. Fantz RL. Visual experience in infants: Decreased attention to familiar patterns relative to novel ones. *Science*. 1964;146(3644):668-670. doi:10.1126/science.146.3644.668

27. Reynolds GD, Roth KC. The development of attentional biases for faces in infancy: A developmental systems perspective. *Frontiers in Psychology*. 2018;9:222. doi:10.3389/fpsyg.2018.00222

28. Reynolds GD, Richards JE. Infant visual attention and stimulus repetition effects on object recognition. *Child Development*. 2019;90(4):1027-1042. doi:10.1111/cdev.12982

29. Dixon KC, Reynolds GD, Romano AC, Roth KC, Stumpe AL, Guy MW, Mosteller SM. Neural correlates of individuation and categorization of other-species faces in infancy. *Neuropsychologia*. 2019;126:27-35. doi:10.1016/j.neuropsychologia.2017.09.037

30. Guy MW, Zieber N, Richards JE. The cortical development of specialized face processing in infancy. *Child Development*. 2016;87(5):1581-1600. doi:10.1111/cdev.12543

31. Xie W, Mallin BM, Richards JE. Development of brain functional connectivity and its relation to infant sustained attention in the first year of life. *Developmental Science*. 2019;22(1):e12703. doi:10.1111/desc.12703

32. Xie W, Richards JE. The relation between infant covert orienting, sustained attention and brain activity. *Brain Topography.* 2017;30(2):198-219. doi:10.1007/s10548-016-0505-3

33. Xie W, Mallin BM, Richards JE. Development of infant sustained attention and its relation to EEG oscillations: an EEG and cortical source analysis study. *Developmental Science*. 2018;21(3):e12562. doi:10.1111/desc.12562
34. Hämäläinen JA, Ortiz-Mantilla S, Benasich AA. Source localization of event-related potentials to pitch change mapped onto age-appropriate MRIs at 6months of age. *Neuroimage*. 2011;54(3):1910-1918. doi:10.1016/j.neuroimage.2010.10.016
35. Ortiz-Mantilla S, Hämäläinen JA, Benasich AA. Time course of ERP generators to syllables in infants: A source localization study using age-appropriate brain templates. *Neuroimage*. 2012;59(4):3275-3287. doi:10.1016/j.neuroimage.2011.11.048
36. Richards JE. *Realistic cortical source models of ERP*. Unpublished manuscript. 2006.
37. Richards JE, Xie W. Brains for all the ages: Structural neurodevelopment in infants and children from a life-span perspective. *Advances in Child Development and Behavior*. 2015;48::1-52. doi:10.1016/bs.acdb.2014.11.001
38. Bulgarelli C, de Klerk CCJM, Richards JE, Southgate V, Hamilton A, Blasi A. The developmental trajectory of fronto-temporoparietal connectivity as a proxy of the default mode network: a longitudinal fNIRS investigation. *Human Brain Mapping.* 2020;41(10):2717-2740. doi:10.1002/hbm.24974
39. Noreika V, Georgieva S, Wass S, Leong V. 14 challenges and their solutions for conducting social neuroscience and longitudinal EEG research with infants. *Infant Behavior and Development.* 2020;58:101393. doi:10.1016/j.infbeh.2019.101393
40. Danielson ML, Bitsko RH, Ghandour RM, Holbrook JR, Kogan MD, Blumberg SJ. Prevalence of parent-reported adhd diagnosis and associated treatment among U.S. children and adolescents, 2016. *Journal of Clinical Child & Adolescent Psychology*. 2018;47(2):199-212. doi:10.1080/15374416.2017.1417860
41. Aman CJ, Roberts RJ, Pennington BF. A neuropsychological examination of the underlying deficit in attention deficit hyperactivity disorder: Frontal lobe versus right parietal lobe theories. *Developmental Psychology*. 1998;34(5):956-969. doi:10.1037/0012-1649.34.5.956
42. Shaw P, Eckstrand K, Sharp W, Blumenthal J, Lerch JP, Greenstein D, Clasen L, Evans A, Giedd J, Rapoport JL. Attention-deficit/hyperactivity disorder is characterized by a delay in cortical maturation. *Proceedings of the National Academy of Sciences of the United States of America.* 2007;104(49):19649-19654. doi:10.1073/pnas.0707741104
43. Posner J, Park C, Wang Z. Connecting the dots: A review of resting connectivity MRI studies in attention-deficit/hyperactivity disorder. *Neuropsychology Review*. 2014;24(1):3-15. doi:10.1007/s11065-014-9251-z