The Early Development of Visual-Spatial Attention

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Introduction

Successful adaptation to our ever-changing world depends on our ability to move attention quickly in space. From very early in life, our ability to selectively orient or redirect attention allows us to connect with key others, to learn about and make sense of the world, and to regulate our emotional reactions.[1,2] As currently conceived, "spatial selectivity" is achieved through the component disengage, shift and engage operations of the posterior visual attention system.[3,4] In order to move attention in visual space and thereby optimize the quality of "new" visual input, the infant must first disengage from the current focus and then shift and engage attention at the new target location, bringing with it the processing resources of the visual system.

Subject

The posterior attention system and its spatially-selective component operations form part of a larger network of interconnected attention systems that are organized at distinct levels and mediated by different neural regions.[3,5] These include both a sub-cortical vigilance system, which maintains alertness and sustained attention, and an anterior (frontal) executive system, which exerts volitional (voluntary) control and recruits resources necessary for goal-directed behaviour. Toward the latter part of the first year of life, development of the *frontal cortex* allows the infant to increasingly exert volitional control over visual-spatial orienting.[6-8] Prior to this, the infant's attention is driven largely by external input, to which responses of the posterior attention system are relatively quick and automatic.

Relevance and Statement of the Problem

Given the fundamental importance of visual orienting to overall adaptation, research has focused on its early development in both typical and atypical populations. Development of the disengage operation is of particular interest because of its critical role, not only in virtually all forms of learning, but also in the regulation of emotion.[1]

When over-aroused by novelty, unfamiliarity or excessive stimulation, infants regulate state by disengaging and moving their attention elsewhere.

Research Context and Key Research Questions

Evidence on the early development of the shift and disengage operations comes largely from a simple visual orienting task known as the "Gap task." In this task, the infant's attention is engaged on a centrally-located attractor stimulus, and then the time taken to initiate an eye movement (saccade) to onset of a second peripheral stimulus is measured. The critical distinction is whether the two stimuli overlap or not. Conditions under which a gap occurs provide a measure of the shift operation: offset of the attractor stimulus prior to onset of the peripheral stimulus serves to automatically disengage attention such that a shift alone is required. Conditions in which the two stimuli overlap (i.e., the two compete for attention) provide a measure of the disengage operation: attention must be disengaged first from the attractor stimulus before it can be shifted to the peripheral stimulus.

This task has been used to address a number of key research questions, notably:

1. When in development does the disengage operation become operative?
2. Is development of the disengage operation associated with infants being easier to soothe? and
3. Are disengage problems early in life predictive of autism, and associated with increased distress/irritability?

Recent Research Results

Typical development

Using variants of the Gap task, findings consistently indicate that the disengage operation becomes operative between 3 and 4 months of age[9-11] (also see[12] for evidence of development into early childhood). Overall, saccadic latencies (reaction times) to disengage and shift attention decrease from 1½-6 months of age. At all ages, responses are slower during the overlap (disengage) than the gap (shift) condition, although this effect is largest in the younger infants. Prior to age 4 months, infants are able to selectively focus their attention, but once engaged on a particular stimulus, they have difficulty disengaging and moving their attention elsewhere. Rather, they tend to fixate for prolonged periods, as captured by the terms "obligatory looking"[13] or "sticky fixation."[14]

While the precise neural circuitry underlying development of the disengage operation remains to be elucidated, evidence of a major change during the first 3-4 months is thought to reflect the increasing influence of cortical input.[15,8,16] At the behavioural level, the ability to disengage attention is implicated in the development of various cognitive and social-cognitive milestones (e.g., back-and-forth looking, as required in discrimination leaning;[17] contingency learning;[10] and joint attention;[18,19] as well as the regulation of state.).[2] Indeed, in 4- to 6-month-olds, ease of disengaging attention is associated with less distress, more positive emotion and with infants being easier to soothe, as measured by parent reports on a temperament questionnaire.[20,10,11] Thus, consistent with the claims of Rothbart et al.,[2] disengagement or distraction appears to be a basic mechanism by which infants regulate their emotional states.

Atypical development

In related work using the Gap task, delays in development of the disengage operation have been documented in various high-risk groups, including infants with William's syndrome and those with frontal lobe injuries.[21,22] In autism and its related disorders (autistic spectrum disorders, or ASDs) ? conditions defined by atypical social-communicative development and a lack of behavioural/cognitive flexibility[23] findings are particularly striking. Children with ASD are distinguished from developmentally-matched controls by long reaction times to disengage visual attention, as well as a preponderance of associated distress or avoidance behaviours (e.g., rapid and shallow breathing, gaze aversion and excessive mouthing).[18,24,25] Note further that in ASD the disengage problem persists into adulthood, and in adults, like children, the problem is particularly marked when moving attention to the left side of space.[26-30] Finally, in research on at-risk infants with an older sibling with ASD, disengage problems at 12 months are predictive of a later ASD diagnosis, and to a lesser extent are characteristic of the broader autistic phenotype (i.e., non-ASD cases) (Bryson SE et al., unpublished data, 2009).[31-33] Again, the ASD cases were distinguished by abnormally long left-directed disengage reaction times, and these were linked with parent-reported temperament, notably low reactivity, high irritability and reduced capacity to be soothed. Both the left-sided asymmetry in disengagement and its association with negative affect implicate right hemisphere dysfunction in ASD, which, given the age of onset of the problem (12 vs. 6 months), may be compromised by impoverished development of frontal/executive control (Bryson SE et al., unpublished data, 2009).

Conclusions, Research Gaps and Implications for Parents, Services and Policy

To summarize, visual-spatial attention and its component disengage, shift and engage operations allow developing infants to selectively orient to key people and events, and to regulate their emotional reactions to incoming sensory information. Findings indicate that these operations develop early in life, and that they become increasingly under the control of the anterior attention system, thus allowing infants to exert volitional control in the face of incoming stimulation. Delayed development of the disengage operation is not restricted to but is particularly marked in children with ASD. Indeed, evidence for both the early emergence and stability of impaired disengagement suggests that this is a core dimension of the autistic phenotype.[34] Among the outstanding questions is whether and to what extent disengagement underlies other key features of development, including the development of joint attention and related social-communicative skills, as well as the ability to flexibly shift set and to process information at both a global and local level.[18,7,34,35]

At the more applied level, learning and adaptation in the typically-developing infant is made possible by the

ability, from very early in life, to control attention and regulate states of emotional distress. Problems with disengagement, often expressed in infants as prolonged visual fixation, together with high levels of distress, are very worrisome and challenging for parents, and should be seen as flags that warrant referral. Early detection and appropriate treatment of these behavioural signs will go a long way in preventing the cascading negative effects so well documented in children with autism and related disorders.[36] Rather, we need to reduce distress and enhance states of positive affect in order to optimize learning and adaptation in all children.

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