Visual attention in the first years: typical development and developmental disorders

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ABBREVIATIONS

ECAB Early Childhood Attention Battery
ADHD Attention-deficit–hyperactivity disorder

The development of attention is critical for the young child's competence in dealing with the demands of everyday life. Here we review evidence from infants and preschool children regarding the development of three neural subsystems of attention: selective attention, sustained attention, and attentional (executive) control. These systems overlap with dorsal cortical visual streams and their disorders are related to the general hypothesis of 'dorsal stream vulnerability'. Infants' ability to control spatial selective attention can be measured using the 'Fixation Shift' task. From around 4 months of age, infants start to show cortical control in disengaging to switch between competing targets. Fixation shifts have proved to be an effective early indicator of attentional disorders associated with perinatal brain damage. Executive function emerges slowly, starting around 1 year of age. The new Early Childhood Attention Battery has identified the three attention subsystems as distinct before 5 years of age in typical development and allows assessment of individual attention profiles across these subsystems. The Early Childhood Attention Battery is now being used to identify specific profiles associated with developmental syndromes such as Williams, Down, and fragile X. These new methods offer the possibility of very early identification of attention disorders, raising the challenge of effective remediation and treatment at an early age.

WHAT IS ATTENTION?

Here we define attention as the ability to deploy the resources of the brain so as to optimize performance towards behavioural goals. These resources can be sensory or perceptual, analysing the most significant and task-relevant stimuli, and can also be spatial in directing processing towards a location that may require action. However, more abstract cognitive resources must also be controlled, such as those which select, operate, and maintain the behavioural rules that are necessary for obtaining a goal in the current task.[1] The development of these abilities is critical for the child's growing competence in dealing with the social, physical, and educational demands of everyday life. Deficits in the ability to direct and maintain attention are often identified in children after early brain injury or very preterm birth, and also in children with genetic developmental disorders. Attention-deficit–hyperactivity disorder (ADHD) is one of the most common problems in typically developing children (over 5% of school children[2]) and has a heavy individual, economic, and social burden which in the USA is estimated at over $30 billion annually.[3]

Most systematic testing of children's attention abilities takes place during the school years. However, attention deficits have their roots in early development in infancy, and there is a serious need to assess children between birth and 6 years of age in order to understand this developmental process and, most importantly, identify individual problems as early as possible, when the brain is most responsive to treatment. Here we review some of the main findings of work on this early age group, considering the normal trajectory of early attentional development and attention impairment in children with neurodevelopmental disorders.

NEURAL BASES OF MULTIPLE ATTENTION SYSTEMS

Functional neural networks of attention

Attention typically involves high-level cortical systems, often including networks in the frontal lobes, which modulate and control the activity of other brain processes, including those in early sensory areas.[4] However, this is not a unitary process. Influential accounts by Posner et al.,[5–7] based on neuropsychological studies of adults and functional neuroimaging, identify three major functional networks. One, through which parietal structures connect with frontal eye fields and the superior colliculus, is concerned with orienting attention in space. This is an important form of *selective attention*, which primes the system to respond to certain types of input and ignore others. A second alerting network, involving the parietal cortex, right frontal cortex, and locus coeruleus, maintains the overall sensitivity of the system to incoming information in tasks demanding *sustained attention*. The third network, including primarily left and right frontal areas and the anterior cingulate cortex, is engaged in *attentional control* or *executive function*, a complex of processes that includes selecting and switching goals, inhibit-

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ing well-established but inappropriate responses, and resolving behavioural conflicts.

Duncan[8] has identified a common pattern of activity in parietofrontal networks, which defines the 'multiple demand' system. This network is active across many cognitive tasks of 'fluid intelligence' and may be the culmination of dynamic interactions between the three component attention networks. A possibility for future research is to investigate how far attention problems may reflect failures of integration between attention systems during development.

Recent approaches to individual differences in attentional abilities have attempted to separate the assessment of these multiple attentional functions (or 'components'). Factor analysis of the components of the Test of Everyday Attention[9] and of a group of tests used by Mirsky et al.,[10] among other data sets, have supported the view that these three networks are systems whose performance can vary independently, although extensions and subdivisions of this set of factors are possible. As the structural development of the brain is not uniform, and because its functions have different developmental onsets and develop at different rates, we would expect these networks to have their own distinctive developmental trajectories. However, there must be dynamic interactions between these three systems throughout development.

Dorsal stream vulnerability: the involvement of attention networks

All these attention networks overlap or interconnect heavily with the extended dorsal stream (or 'streams') of cortical visuospatial processing.[11,12] Measures of global coherence sensitivity to a static form or pattern compared with sensitivity to motion have been used as signatures of comparative functioning in the ventral and dorsal streams. We have hypothesized the existence of 'dorsal stream vulnerability', reflected in deficits in motion processing compared with static pattern processing, suggesting that development in the dorsal stream is more vulnerable than that in the ventral stream. This relatively poor dorsal stream functioning is found in a wide range of acquired and genetic developmental disorders,[13,14] and is consistent with the prevalence of attention problems in these disorders.

INFANT ORIENTING AND ATTENTION SWITCHING

Typically developing infants in the first months of life can shift fixation from a central target to a salient target appearing in the periphery, provided that both targets are not visible together and there are no other visual or auditory 'distractors' in the rest of the visual field.[15,16] We have proposed that subcortical systems, involving the superior colliculus, underpin this initial attentional ability of newborn infants.[16–18] At a few months postterm, cortical systems begin to play a role, enabling infants to disengage attention from one visual object of interest and foveate a newly appearing target.[16] This 'Fixation Shift' test[16] compares an infant's ability to make such a shift when a central target disappears as a lateral target appears ('non-competition') with the ability to shift fixation in the 'competition' condition in which the central target remains visible. Figure 1 shows how the time required for typically developing infants up to 3 to 4 months of age to disengage and shift attention is much longer in the competition than in the 'non-competition' condition. We confirmed the role of cortical systems in disengagement and attention shifting by studying infants who had undergone hemispherectomy to relieve intractable epilepsy. These infants could make lateral fixation shifts to either side in the non-competition condition, but not to the visual field when there was no cortical representation in the competition condition.[19] This fixation shift paradigm has also been shown to be a sensitive indicator of cerebral injury and is predictive of neurocognitive outcome in children with perinatal brain damage such as focal lesions,[20] hypoxic–ischaemic encephalopathy,[21–23] or perinatal abnormality of white matter associated with very preterm birth.[24] It has also been used successfully to assess attention in relation to other aspects of visuocognitive development in children with West syndrome[25] and Williams syndrome.[26] It has the advantage over some similar tests which have more recently been developed (e.g. the gap-overlap paradigm[27]) in giving a pass/fail measure for each individual child and in being established for use over a relatively wide age range (from birth to age 2y for typical development and individuals with equivalent mental age with atypical development).

This approach takes overt eye movements as an indicator of attention. However, from around 6 months of age the latency of fixation shifts is affected by brief preceding stimuli, which induce positive cueing or negative 'inhibition of return'.[28,29] As these stimuli do not directly induce eye movements, the effects are taken as evidence for covert processes of spatial attention which prepare the system for a subsequent saccade.

What this paper adds

- New methods make it possible to assess distinct components of attention in infants and preschool children.
- Distinctive profiles of attention can be characterized in different developmental disorders.
- Developmental disorders of attention are associated with the vulnerability of the dorsal cortical stream.

SUSTAINED ATTENTION IN INFANCY

An extensive body of work has studied the maintenance of sustained attention in infants' inspection of visual stimuli. Distinctive electrophysiological, heart rate, and behavioural responses occur while attention is maintained and while it is being terminated.[30] These phenomena are closely related to the phenomenon of habituation, in which novel stimuli elicit orientating and sustained looking that declines with repeated presentation. The rate of habituation has been offered as an indicator of cognitive differences among young infants.[31] However, it suffers from the difficulty that a short looking time may reflect either efficient processing of the stimulus or a 'short attention span', which is the inability to sustain attention long enough for such processing. Although psychophysiological indicators may help to distinguish these possibilities,[32] they have not generally been applied when habituation measures have been used.

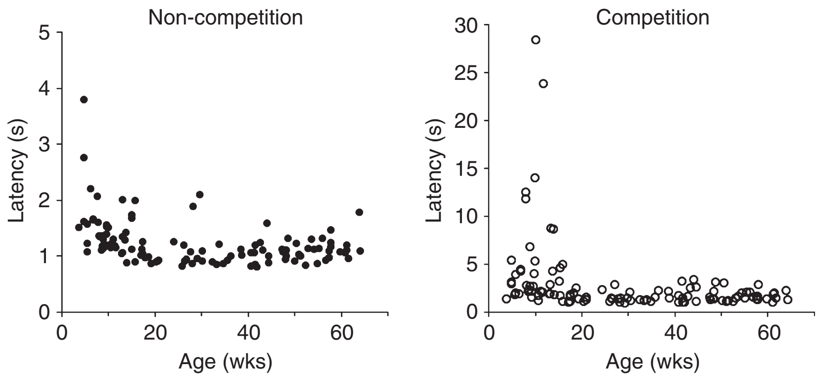

Figure 1: Infants' fixation shift performance as a function of age: mean time to shift fixation in `Non-competition' and `Competition' conditions. Each infant is represented by one point in each condition. Note the difference in vertical scale: in infants up to 20 weeks, time under competition (central target remains visible) is much longer (up to 30s) than time under `non-competition' (central target disappears as peripheral target appears). (Unpublished data from Atkinson, Braddick, and Wuensche).

DEVELOPMENT OF EXECUTIVE FUNCTION IN INFANCY

Executive control is often regarded as a function (or set of functions) associated with the prefrontal cortex and emerges slowly in development, reflecting the long-drawn-out maturation of this area.[33] For example, performance of the 'day–night' task,[34] which requires children to inhibit a well-established naming response to picture cards, gradually improves in children between the ages of 3 and 7 years, and the ability to inhibit a direct reaching response, when an object can be retrieved only by an indirect detour, is typically achieved by around 4 years of age.[35] However, a number of researchers have suggested aspects of infant behaviour that may reflect in infancy the development of prefrontal inhibitory mechanisms. For example, a well-known phenomenon of cognitive/behavioural development is the 'A-not-B (place) error', first identified by Jean Piaget.[36] Infants aged 10 to 12 months can successfully retrieve a toy from one hiding place but will continue to search in the original hiding location even when they see the toy being hidden in a new location. Diamond and Goldman-Rakic,[37] comparing infants' behaviour on this task with that of monkeys with prefrontal lesions, proposed that, in overcoming the error, infants have to develop prefrontal systems that serve to sustain the goal and inhibit the tendency to use a familiar ('prepotent') response. More recently, the learned ability to delay a shift of fixation[38] and learning to avoid shifts from a dynamic target to distractors (the 'freeze-frame' task[39]) have been taken as indicators of prefrontal inhibition in infants as young as 5 and 9 months respectively. This ability to inhibit in infants has been found to correlate with a spatial conflict task on the same children at the age of 2 years. This evidence for components of prefrontal executive function in the first year of life, at least in oculomotor behaviour, does not diminish the evidence that, overall, prefrontal systems have been found to be relatively slow to develop, both structurally and functionally, in the human brain.

THE PROFILE OF ATTENTIONAL ABILITIES IN DEVELOPMENT: THE EARLY CHILDHOOD ATTENTION BATTERY

We have seen that 'attention' refers to a combination of multiple different abilities, subserved by separate but interlinked component neural systems. For this reason, we need to study and assess children's profiles across these abilities if we are to understand the typical development of attention and identify the significant problems associated with developmental disorders.

Many studies have demonstrated age-related improvements in individual components of attention: selective attention,[40,41] sustained attention,[42–44] and attentional control or executive functions.[34,45–47] It has been suggested that these domains of attention can be differentiated by their distinct developmental trajectories.[48–50] This view gains support from the factor analysis of multiple attention tests with children, similar to that reviewed above with adults. This method has been used to define subtests of the Test of Everyday Attention for Children (TEA-Ch),[51] which was developed for typically developing children older than 6 years, that are weighted towards each of the three components.

However, there is a strong need for the same approach in the preschool age range. The new Early Childhood Attention Battery (ECAB), which we have developed (Breckenridge et al., unpublished data; Breckenridge et al.[52]) aims to apply similar principles in a set of tests whose demands are appropriate for young children in the developmental age range of 3 to 6 years, maximizing developmental sensitivity and minimizing confounds from non-attentional demands such as the ability to count.

The ECAB has been normalized for a large group of typically developing 3- to 6-year-old preschool children. Its broad validity has been confirmed by a strong correlation with TEA-Ch scores in a group of children tested at the age 6 to 7 years, 7 to 15 months after their ECAB assessment. Factor analysis across the ECAB subtests for children aged 4 years 6 months to 6 years showed a similar trio of components (selective attention, sustained attention, and attentional control) to those found in older children and adults. However, the results for children aged 3 to 4 years 6 months showed only two factors, with considerable overlap between them. This may reflect a true differentiation of the underlying brain systems in the course of preschool-age development; alternatively, it is possible that performance in the younger group is constrained by some overall limitation (e.g. memory, basic processing speed) which masks any separate contributions of distinct subsystems. In any case, the results confirm that a multidimensional approach to attention is feasible in the preschool age range and provide a practical instrument for defining children's individual attentional profiles, including children with developmental disorders at an equivalent developmental stage to typically developing preschool children. Some results with developmental disorders are discussed below.

The approach taken here distinguishes the components of attention from working memory. However, working memory is intimately associated with executive function, and its development must interact with attention in determining performance on many cognitive tasks.[53,54] It has been found to correlate with planning but not with inhibitory aspects of executive function in preschool children; however, inhibition rather than planning or working memory was associated with early ADHD symptoms.[55] The extent to which working memory is a separable factor from the components of attention over the preschool age range remains a matter for further research.

DEFICITS OF ATTENTION IN INFANTS AND PRESCHOOL CHILDREN

Most of the literature on developmental disorders of attention has concentrated on school-age children. Here we will focus primarily on attentional deficits in preschool children with perinatal problems, for example children born very preterm and/or small for gestational age, and some with specific genetic syndromes. Some results on the sensitivity of the fixation shift test to perinatal brain damage in term-born infants have been cited earlier in this review.

Attention deficits in children born preterm and/or small for gestational age

Neurocognitive impairment is a frequent result of birth before 32 weeks' gestation, with damage to developing oligodendrocytes via ischaemic events and/or early infections leading to white matter injury.[56] Recent reviews[57,58] highlight attention problems as a focus of particular concern related to preterm birth, and even moderate preterm birth (32–36wks' gestation) carries a higher risk of later attentional disorders than term birth.[59]

Effects associated with low birthweight may be distinct from those of preterm birth per se. ADHD has been found to be four times more common in children with a low birthweight than in comparison children at the age of 11 years.[60] A regression analysis found that ADHD symptoms were associated with being small for gestational age rather than preterm birth,[61] with early fetal growth restriction possibly the precursor of the delays and abnormalities of brain development reported in ADHD.[62]

Deficits of attention after very preterm birth can be identified early in life. A follow-up of a cohort of preterm children on age-appropriate executive function tests at 2 to 5 years (including the detour box[35] and counterpointing[26] tasks) showed that over 70% failed relative to age norms.[63] A larger cohort from the same source, tested at the age of 6 to 7 years,[63] scored markedly below norms on subtests of the TEA-Ch[51] on inhibitory control and visual search, despite normal results on the Wechsler Preschool and Primary Scale of Intelligence. In line with the dorsal vulnerability hypothesis, these attentional deficits were part of a cluster of marked deficits including spatial cognition, visuomotor coordination, and visual motion and stereo processing, all of which are functions associated with the dorsal stream(s). Many of these areas showed correlation with the severity of magnetic resonance imaging findings at term. A major meta-analysis, which includes results from older children,[57] suggests that although children born preterm may catch up with term-born children on selective attention performance, their deficits on executive function remain or increase with age.

Attention in genetic developmental disorders

Problems with attention, including distractibility and impulsivity, are a prominent and enduring feature of genetic disorders which affect cognitive development, for example in children with Williams syndrome, Down syndrome, and fragile X syndrome. Given that these disorders have distinctive cognitive profiles, we need to ask whether these attention difficulties reflect anything more than the children's general level of mental age, and whether they show any specific profile across the components of attention.

A selective attention deficit is apparent in young children with Williams syndrome that has been identified through long latencies under competition in the fixation shift task[26] and anomalies in saccade planning.[64] Their difficulty in disengaging is distinctive from toddlers with fragile X, whose difficulties are in inhibiting shifts.[65] Visual search tasks also demand selective attention, albeit in a more complex context. Here too syndromes are distinctive, with Williams syndrome toddlers overselecting non-target items; children with fragile X syndrome make perseverative errors with targets that they have already identified,[41] while children with Down syndrome perform similarly to mental age-matched children.[65]

Attentional control appears to be an area of particular difficulty in which children with Williams syndrome generally perform below their mental age level, with scores correlated across a range of 'frontal' tests.[26] However, this deficit is not uniform across domains. In line with their marked imbalance between verbal and visuospatial cognition, children with Williams syndrome demonstrated their greatest deficit as inhibiting responses that had a spatial component, such as counterpointing (pointing a finger to the opposite side [left–right] of a screen to that where a target appears) and detour reaching (a ball must be retrieved by operating an indirect device, not by reaching directly for it).[26] On a verbal task, inhibiting a familiar name,[34] children with Williams syndrome performed in line with or even better than mental-age-matched children.[26] There are data suggesting that this visual versus verbal discrepancy on attentional control tasks is reversed in Down syndrome.[66]

The new ECAB, discussed above, is designed to give a profile across the domains of attention for developmental ages between 3 and 6 years, which is the appropriate range for many older children and adolescents with Williams syndrome, Down syndrome, and fragile X syndrome.

An ECAB study of Williams syndrome and Down syndrome groups[52] has enabled such profiles to be determined and compared. Figure 2 illustrates that, in both Williams syndrome and Down syndrome, attention scores tended to be below the overall cognitive level indicated by Weschler Preschool and Primary Scale of Intelligence test scores. However, sustained attention was a relative strength, with both groups performing at or above their mental age. In visual search tasks, response inhibition tasks (counterpointing and verbal opposites), and task switching, both groups performed significantly below their mental age. Visuospatial response control in the counterpointing task was a particular weakness for the group with Williams syndrome, which is consistent with earlier findings,[26] but much less so for children with Down syndrome. Both groups also showed significant deficits on the ECAB set-shifting task, indicating problems of perseveration. Overall, therefore, the profiles are quite uneven, with attentional control tasks showing the greatest impairment and the spatial difficulties in Williams syndrome amplifying this deficit. The results confirm that these developmental disorders have a greater impact on attention control (executive function) than would be appreciated from standardized measures of mental age. Intelligence tests require short periods of focus on tasks controlled by the tester, and so may underrepresent the attention control functions that are central for meeting the demands of self-directed and self-regulated everyday life.

However, these disorders are characterized not by static profiles but by developmental trajectories. Infants with Down syndrome appear to show early sustained attention deficits, whereas infants with Williams syndrome do not;[64] the opposite has been found for selective attention.[65] The ECAB study, at an average chronological age of 8 to 9 years, found sustained attention around the mental age level but selective attention below the mental age level in both groups. A fuller account of these trajectories will hopefully give an insight into the cascade of events that leads to the final cognitive phenotype in each disorder.

TRAINING AND REMEDIATION

The capability to assess children's attention development at an early age will be of most value if it can be used to target effective interventions. There is much interest in procedures for training attention and executive function. Rueda et al.[67] reported successes with 4- and 6-year-olds in a graded set of visuomotor and cognitive exercises focused on enhancing inhibitory control; the training effect was stronger in the children with initially poorer scores and, interestingly, this was related to polymorphism in a dopamine transporter gene.

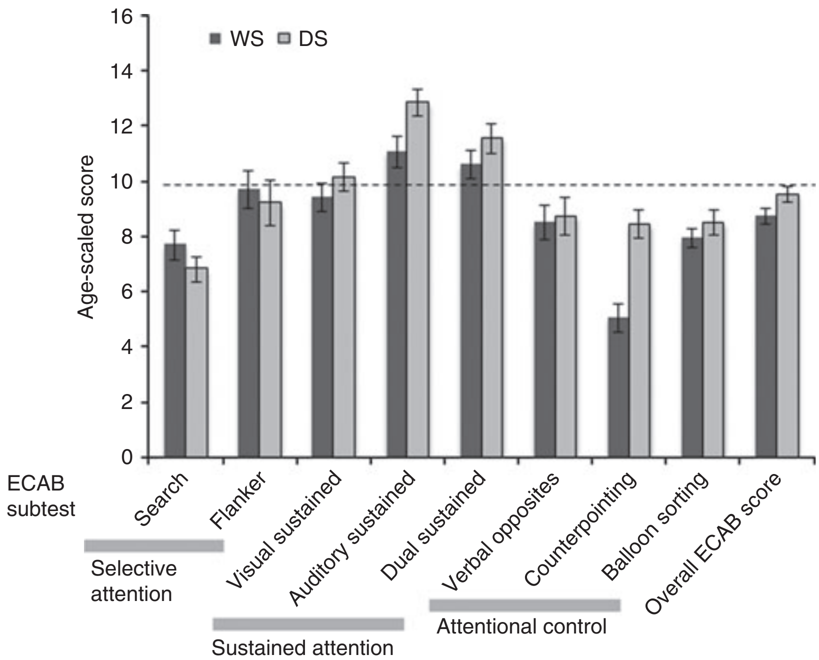

Figure 2: Mean scores of groups with Williams syndrome (WS) and Down syndrome (DS; chronological age, 5–15y; mental age, 3–6y; *n*=32 in each group) on individual subtests of the Early Childhood Attention Battery (ECAB) grouped according to the three components of attention. The rightmost bars show the overall scores. Scores are scaled for mental age norms so that 10=expected mean score for cognitive age. Error bars=standard error of mean (see Breckenridge et al.[53]).

Diamond et al.[68] evaluated an educational programme, 'Tools for the Mind', which aims to enhance self-regulation in kindergarten children, and found that it improved 5-year-olds' performance on attentional and inhibitory tasks without explicit training on these. Most recently, 11-month-old infants' experiences with displays that encouraged them to sustain fixation and ignore distractors (e.g. by maintaining the movement of a butterfly image so long as the infant is fixating it) have been reported to improve independent measures of fixation control taken on a separate day.[69] The value of such effects needs to be assessed in terms of how far they can be generalized to the demands of everyday and school life, how effective they are in children with developmental disorders, and how long they last. However, such results give some hope that assessment of impaired attention in early childhood may not only be practical but also eventually guide effective therapies.

CONCLUSION

The advances we have discussed make it possible to assess and differentiate attention abilities in infants and preschool children and to assess attention in children with developmental delays and disorders whose 'mental age' is in this age range. Further research is needed to determine how far these measures can predict the diagnosis of ADHD at school age. Such assessment should help to identify cognitive strengths that can be built upon and areas of deficit that require remediation. Successful remediation is an area with some promising results but is in need of longer term development and evaluation.

Any assessment requires that the child should find the task motivating. The tests we describe are designed to do this, but there are wide variations in what engages the interest of individual children. We need to be alert to such individual preferences and to exploit them, both for assessing the child's fullest potential and to provide the optimal basis for individual training programmes.

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