Attention development in infants and preschool children born preterm: A review

Eva van de Weijer-Bergsma *, Lex Wijnroks, Marian J. Jongmans

Langeveld Institute for the Study of Education and Development in Childhood and Adolescence, Utrecht University, Heidelberlaan 1, 3584 CS Utrecht, The Netherlands

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Abstract

A potential mechanism that can explain preterm children’s heightened risk for the development of later cognitive and behavioral problems is attention. Attention is the ability of an infant or child to orient to, to shift between and to maintain focus on events, objects, tasks, and problems in the external world, processes which are all dependent on the functioning of attentional networks in the brain. The aim of this paper is to provide a review of the literature on attention development in children born preterm during the first 4 years of life. First, research examining the differences between preterm and full-term children indicates that early attention development in infants born preterm is less optimal and that these differences increase when infants grow into toddlers. Second, studies investigating individual differences within preterm populations reveal the influence of both biological factors and environmental factors. Third, individual differences in early orienting and sustained attention have been shown to be predictive of later attentional, cognitive and behavioral functioning in children born preterm. The importance of long-term follow-up studies, with a focus on individual developmental trajectories in orienting, sustained and executive attention, is emphasized.

Keywords: Preterm birth; Attention development; Infancy; Preschool age; Risk and protective factors

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* Corresponding author at: Langeveld Institute for the Study of Education and Development in Childhood and Adolescence, Utrecht University, PO Box 80140, 3508 TC Utrecht, The Netherlands. Tel.: +31 30 2537681; fax: +31 30 2537731.
E-mail address: e.vandeweijer@uu.nl (E. van de Weijer-Bergsma).

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Due to medical advances, there is an increased survival rate in children who are born preterm (gestational age < 37 weeks) and/or have a low birth weight (LBW < 2500 g) (Stoelhorst et al., 2005). However, especially those infants born preterm who have a very low birth weight (VLBW < 1500 g) or extremely low birth weight (ELBW < 1000 g) are at risk for developmental problems (Anderson & Doyle, 2003; Aylward, 2002a, 2005; Bhutta, Cleves, Casey, Cradock, & Anand, 2002; Salt & Redshaw, 2006). Although major disabilities (e.g. mental retardation, sensory disorders and cerebral palsy) are often detected during infancy and their incidence has remained constant, low severity dysfunctions (e.g. learning disabilities and ADHD) become more apparent when children grow older (i.e. at school age) (Aylward, 2005; Luciana, 2003), and their incidence has increased (for a review see Aylward, 2002a). Moreover, even children born preterm without apparent disabilities and who have intellectual abilities within the normal range, receive special educational services at a very high rate (Aylward, 2002a; Walther, den Ouden, & Verloove-Vanhorick, 2000).

Until now, many efforts have been made to investigate factors associated with developmental dysfunction in children born preterm. Many studies have concentrated on neonatal risk factors such as birth weight (BW), gestational age (GA), and medical complications. However, there are limitations to the conclusions that can be drawn from these studies. First, although associations with BW, GA and the severity of medical complications have been found (Aylward, 2002a; Cohen, Parmelee, Sigman, & Beckwith, 1982; Cooke, 2006; Hack et al., 2000; Short et al., 2003; Vohr et al., 2000; Wood et al., 2000), correlations are relatively low and therefore explain only little variance. Moreover, these biomedical factors are interrelated, making interpretations about their relative contribution difficult. Secondly, many studies have concentrated on global outcome measures, using scores on developmental assessments, such as the Bayley Scales of Infant Development (Bayley, 1969) or intelligence scores. A major problem with interpreting the results from such global measures is that they are often poor predictors for later functioning (Hack et al., 2005; Siegel, 1989; Slater, 1995), because these measures usually appeal to various underlying functions and abilities. As a result, there is a gap in our understanding of the underlying deficits or processes that cause developmental problems in children born preterm.

A third limitation is related to the use of comparisons between preterm and full-term groups. The finding that children born preterm, as a group, lag behind, when compared to children born at term, does not explain the variability within the group of children born preterm, or why some of these children even outperform children born at term. Moreover, it is difficult to interpret differences between children born preterm and children born at term, since we do not know whether the observed deficits are permanent or temporary delays followed by catch-up. Although some studies suggest that deficits in infants born preterm are structural during early childhood, or even become worse when children grow older (Aylward, 2002a; Koller, Lawson, Rose, Wallace, & McCarton, 1997), others have reported catch-up in some preterm subgroups (Taylor, Minich, Klein, & Hack, 2004; Tideman, 2000).

A potential mechanism that can explain a heightened risk for developmental problems and within-group variability among children born preterm is attention. By attention we mean the attention an infant or child has for events, objects, tasks, and problems in the external world, which is dependent on the functioning of attentional networks in the brain (Posner & Petersen, 1990; Posner & Raichle, 1994). Because infants and young children are confronted with a complex environment filled with vast amounts of stimulation, they need to be selective in what they attend to and responsive when important events occur, in order to function well. Also, they have to learn to show persistence to complete tasks despite obstacles and distractions, but at the same time be able to disengage attention from activities that are ineffective (Ruff & Rothbart, 1996). The development of attention has been studied from different viewpoints. Whereas some studies emphasize the cognitive products of visual attention, other focus on the process of attention in itself (Colombo, 2004). First and originally, attention measures have been used as a tool to study the development of other cognitive abilities, such as recognition memory and habituation (i.e. products of attention). Second, due to advances in cognitive neuroscience, attention development per se and associated brain development has sparked interest (i.e. process of attention). Also, research with clinical populations has triggered interest for the predictive value of early attention for future dysfunction in attention and other areas. For example, the finding that school-aged children, who were born preterm, are at risk for attention difficulties possibly leading to a diagnosis of ADHD (Aylward, 2002a; Bayless & Stevenson, 2007; Bhutta et al., 2002; Mick, Biederman, Prince, Fischer, & Faraone, 2002; Salt & Redshaw, 2006) has led researchers to propose that early problems in the regulation of attention may underlie the individual variability between infants born preterm and their vulnerability as a group for developmental delay and learning problems (Aylward, 2002a; Davis & Burns, 2001).

Therefore, the aim of the present paper is to provide a review of studies investigating the development of attention per se (i.e. the process of attention) in infants and preschool children who were born preterm. First, early attention development in typically developing children will be described from a cognitive neuroscience perspective. Second,
literature on attention development in children born preterm will be evaluated. We aim to (1) identify differences in attention development during infancy and the preschool years between children born preterm and children born at term, (2) distinguish important environmental and biological predictors of attention development in children born preterm, and (3) examine the predictive value of early attention development for later functioning in children born preterm.

1. A cognitive neuroscience perspective on early development of attention

An influential neuropsychological model of attention development that covers the entire life span was proposed by Posner and co-workers (Posner & Petersen, 1990; Posner & Raichle, 1994). According to this account there are three interconnected attention networks in the brain, including (1) the orienting system or posterior attention network, (2) the alerting or arousal system, and (3) the executive control system or anterior attention network.

The orienting system, consisting of a spatial orienting network in the parietal cortex and an object recognition pathway in the temporal cortex, becomes fully functional during the first 6 months of life, is related to the orientation or movement of attention toward specific locations in the environment and involves a number of behavioral processes, including disengagement, shifting, inhibition of return and anticipatory eye movements (Johnson & Tucker, 1996). Orienting can occur overtly (observed by saccades in eye movements) and covertly (without eye movements). Whereas overt shifts of attention can be observed directly, covert shifts of attention are inferred from the faster detection of targets after a cue. Although this distinction suggests two discrete processes, in daily life covert and overt shifts of attention often occur together (Butcher, 2000; Klein, 2004). A large amount of our knowledge on overt orienting in infancy comes from long-established paradigms such as habituation, novelty preference, and violation of expectation (VEXP) paradigms. Although these paradigms are often referred to as visual attention paradigms, they are originally designed to investigate the development of other aspects of cognition, such as speed of information processing or recognition memory. However, in trying to capture the underlying processes that can explain individual differences in these cognitive abilities, researchers have concentrated on different aspects of visual attention during these tasks, besides the main outcome measures such as habituation rate and novelty preference. These attention measures include look duration (longest look and mean looking time), and changes of attentional focus (shifts of gaze between paired targets). Longer look durations and slower shift rates are considered to be indicative of less efficient disengagement and shifting of attention (Colombo, 2002, 2004; Rose, Feldman, & Jankowski, 2001). More recently, marker tasks for several brain regions involved in the development of orienting of attention have been developed, such as disengagement tasks, the visual expectation paradigm (VEXP), and inhibition of return (IOR) (Johnson, 2005; Johnson, Posner, & Rothbart, 1991; Posner & Raichle, 1994). Disengagement tasks are used to measure an infant’s ability to disengage gaze and attention by adding a peripheral stimulus to a central fixation stimulus. To be able to orient to the peripheral stimulus an infant has to disengage its attention from the central stimulus (Johnson et al., 1991). The visual expectation paradigm (VEXP) is used to measure the ability to direct attention based on expectations, in contrary to the reactive attention based on the presentation of stimuli itself. By presenting stimuli in regular alternation patterns on the left- or on the right-hand side of the infant, the ability to form expectations and make anticipatory eye movements is measured (Johnson et al., 1991; Posner & Raichle, 1994). Although anticipatory attention is controlled by internal processes, in this simple form it is considered part of the orienting system (Posner & Raichle, 1994; Ruff & Rothbart, 1996). The IOR paradigm is used to investigate the tendency not to shift back attention to a recently attended location, by presenting a target stimulus more than 300 ms after a cue. As a result, target detection is slower at the cued location than at the uncued location. This phenomenon is assumed to encourage orienting toward novelty. IOR can be used to investigate the tendency not to shift back attention after overt orienting (by replacing a central stimulus for a peripheral cue for 3 s), and it can also be used to investigate IOR after covert orienting (by adding a cue to the central stimulus for 100 ms) (Butcher, 2000; Johnson, 2005).

The alerting or arousal system, involves parts of the brainstem and later in development also the right frontal lobe, and is related to the capacity to maintain a state of alert arousal, enabling effortful processing of information. Knowledge about the development of this network during infancy and early childhood mainly comes from the behavioral observation of sustained attention (sometimes also called focused attention or focused exploration) during free play, video watching and more or less structured tasks. The behavioral observation of sustained attention is based on the assumption that it is accompanied by (1) a narrowing or restriction of selectivity to fewer elements, and (2) an increase in the degree of effort or energy that is directed at the target task (Ruff & Rothbart, 1996). Sustained attention during free play, for instance, is defined as episodes of manipulation of a toy while looking at the toy with a serious facial
expression (Ruff & Lawson, 1990). The observation of off-task behavior (measured by pauses and exposure times) during habituation or novelty preference paradigms can also be viewed as an indirect measure of sustained attention (Rose, Feldman, McCarton, & Wolfson, 1988).

Several neuropsychological models of attention development agree that the development of attention is accompanied by a (gradual) shift from subcortical processing to increasing cortical control over attention (Colombo, 2001, 2002; Johnson, 2005; Posner & Petersen, 1990; Posner & Raichle, 1994). When infants develop into toddlers, the executive control system begins to mature, involving areas of the frontal cortex, in particular the prefrontal cortex. During this period, attention becomes more related to planned, self-generated activity with objects. Functions associated with higher level control of attention overlap with the more general domain of executive function (EF), which also includes working memory, planning, switching and inhibitory control. In fact, some researchers suggest isomorphic relationships between executive attention and other executive functions, such as working memory, switching and fluid intelligence (Engle, 2002; Kane & Engle, 2002). Because there are no tasks available that purely measure executive attention in infants and preschool children, executive attention is most frequently assessed using marker tasks of the dorsolateral prefrontal cortex (DLPC), a brain area that is involved in several executive functions, such as working memory, inhibition and executive attention. Marker tasks of DLPC functioning in infancy and early childhood are, for example, delayed-response-type tasks, such as the classical A-not-B (AB) task (Diamond & Goldman-Rakic, 1989), in which infants have to retrieve a hidden object from one of two (or more) locations following a delay, after which the location of hiding is changed. Other similar tasks are Delayed Alternation and Spatial Reversal in which a reward is hidden out of the child’s sight and the side of hiding is changed, either alternating between the left and right location, or changing sides after a criterion of consecutive correct retrievals, respectively (Espy et al., 2002).

The development of these three attention networks is described by Ruff and Rothbart (1996). From their extensive review of the literature it has, for example, become evident that infants are selective in their attention from the first day of life, looking longer at some pictures or designs than others. During the first year of life, when the orienting network becomes functional, attention is governed by the novelty of objects and events encountered by the infant, but repeated experience reduces novelty and leads the infant to notice new details and information. Although very young infants are very selective in their attention, they may have much difficulty disengaging from highly salient stimuli. This phenomenon is also called ‘sticky fixation’ or ‘obligatory attention’. Initially, from birth to 8 or 10 weeks of age, looking duration increases, possibly due to the emergence of alertness. From 3 to 5 or 6 months looking duration decreases, reflecting improved ability to disengage attention (Colombo, 2001, 2002). Although most shifts in attention seem to be reactive during this period, infants become able to make anticipatory eye movements based on expectations around this age. Around 7 months of age there are other contexts, such as when infants show manipulative play with several toys or objects simultaneously, in which the length of looking increases with age, reflecting increased sustained or focused attention, which enables infants to explore objects in the environment. This is the result of the increasing influence of the emerging executive control system over the arousal system. A dramatic transition of attention behaviors is observed around 18 to 24 months, when the frontal cortex is undergoing further development. During this period children show a further increase in looking during play, and looking at complex visual displays, such as television. Besides their growing ability to manage attention in the face of potential distracting features when they are playing with several toys at once, infants become more able to plan and self-generate the direction of their attention, by facilitating or inhibiting lower level processes. During the preschool years, when children are confronted with more occasions where they have to attend to events that are intrinsically uninteresting, a higher-level control of attention becomes even more apparent. The ability to plan ahead and engage in complex activity further develops and supports the sustaining of attention when more external demands are placed on the child.

2. Attention development in infants and preschool children born preterm

In the following sections the development of attention in infants and preschool children born preterm will be described. First, studies comparing performance of children born preterm and children born at term will be discussed. Second, risk and protective factors that may be predictive of early attention development within the preterm population will be investigated. Finally, we will examine the predictive value of early attention development for later functioning in children born preterm. In this paper the focus is on research using behavioral measures of visual attention during the first 4 years of life. Studies are included when they fit Posner’s model of attention networks and when one of the tasks or paradigms described in Section 1 (A cognitive neuroscience perspective on early development of attention)
has been used. Studies using habituation, novelty preference or VExP paradigms are only discussed when one or more of the underlying visual attention processes, that were mentioned earlier, are investigated. Since our primary focus is on visual attention of the infant or preschool child in itself, and not on attention skills during interaction with parents, studies investigating joint attention or exploratory play as a direct function of maternal scaffolding will not be subject to review. Information about sample characteristics and measurements used in the studies described in this review are presented in Tables 1a and 1b.

The articles in this review were selected using the keywords “preterm”, “premature”, “birth weight”, “attention”, “sustained”, “focused”, “executive”, “orienting”, “cognitive”, and “development”, during an online computer search in PubMed, SCOPUS and Google between June 2006 and June 2007. After a first selection, an extended search was done based on the reference list of the selected articles.

2.1. Comparison of early attention development between children born preterm and children born at term

2.1.1. The orienting system

Studies using marker tasks of visual orienting indicate that infants born preterm exhibit less efficient attention behaviors than infants born at term during the first 6 months of life (Butcher, 2000; Butcher, Kalverboer, Geuze, & Stremmelaar, 2002; Hunnius, 2004; Stroganova, Posikera, & Pisarevskii, 2005; Stroganova, Posikera, Pisarevskii, & Tsetlin, 2006a, 2006b). For example, even though both low- and high-risk infants born preterm initially showed faster gaze shifts than infants born at term in a study by Butcher et al. (2002), and all groups displayed similar developmental trajectories between 6 and 26 weeks of age in simple gaze shifting as well as in disengagement from an attended stimulus, two observations led the authors to conclude that both groups of infants born preterm disengaged less efficient than the full-term group. First, infants born preterm continued to display a less mature form of errors with increasing age, by persistent staring at the fixation stimulus, in contrast to infants born at term, who increasingly made errors away from the target at older ages. Second, infants born preterm showed less errors than infants born at term. Although this latter finding may seem to indicate superior performance, Butcher et al. (2002) argue that the type of errors the full-term group made indicate more mature inhibition of not only attention to the fixation stimulus but also the inhibition of a response to a highly salient peripheral target in order to look to another, apparently more attractive location. Less mature errors by infants born preterm were also found in a study by Hunnius (2004). Again infants born preterm shifted gaze faster than their full-term born peers initially, but this effect diminished after 16 weeks of age. In addition, infants born preterm showed less mature shifting behavior, and were more inclined to continue staring at the fixation stimulus, despite similar developmental trajectories in gaze shifting frequency when compared to infants born at term. Hunnius (2004) was able to demonstrate that it were abstract stimuli in contrast to facial stimuli that posed a particular challenge for infants born preterm. The tendency in infants born preterm to be captured by stimuli was also observed in a study investigating IOR following covert orienting (Butcher, 2000). Again Butcher (2000) showed that both groups followed the same developmental trajectories in IOR following covert orienting, and that although infants born preterm demonstrated fewer errors than infants born at term, infants born preterm had more difficulty suppressing looks to the cue that had already been covertly attended to.

The results from VExP paradigms, another marker task, indicate that infants born preterm show similar abilities to make an anticipatory eye movement on the basis of a regular pattern of events, compared to infants born at term (Rose, Feldman, Jankowski, & Caro, 2002b), but have more problems maintaining their anticipatory attention than infants born at term (Stroganova et al., 2005, 2006a, 2006b). For example, Rose, Feldman, & Jankowski (2002a) found similar frequencies in anticipatory eye movements in 5-, 7-, and 12-month-old infants born preterm and infants born at term. A more recent study by Stroganova et al. (2005) confirmed these findings in 5-month-old infants born preterm, but also found that infants born preterm had more trouble maintaining anticipatory attention (i.e. maintaining gaze fixation after anticipatory eye movement) than infants born at term. These problems with maintaining anticipatory attention were associated with a relative deficit in the functional synchronization of activity in the lower temporal areas of the cortex (Stroganova et al., 2006a), and a lack of active up-regulation of parasympathetic heart rate (Stroganova et al., 2006b) in infants born preterm.

The finding that infants born preterm display less efficient disengagement and shifting of attention is supported by studies investigating habituation and novelty preference, in which longer looking durations and slower shift rates are considered to reflect less mature attention skills (Bonin, Pomerleau, & Malcuit, 1998; Landry, Leslie, Fletcher, & Francis, 1985; Rose et al., 1988, 2001, 2002b; Ross, Tesman, Auld, & Nas, 1992). Although some researchers failed
### Table 1a
Sample characteristics of preterm (sub)groups

<table>
<thead>
<tr>
<th>Authors</th>
<th>Preterm (sub)group(s)</th>
<th>n</th>
<th>Neonatal medical status</th>
<th>GA</th>
<th>BW</th>
<th>Exclusion criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonin et al. (1998)</td>
<td></td>
<td>34</td>
<td></td>
<td></td>
<td></td>
<td>CNS disorders, congenital malformation syndromes, BPD, IVH I, 5 min Apgar &lt; 5, assisted ventilation &gt; 28 days</td>
</tr>
<tr>
<td>Butcher (2000)</td>
<td>PVE &lt; 14 days</td>
<td>11</td>
<td></td>
<td></td>
<td></td>
<td>IVH I, ROP, NBR score ≥ 5</td>
</tr>
<tr>
<td>Butcher et al. (2002)</td>
<td>PVE ≥ 14 days</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>IVH I, ROP, NBR score ≥ 5</td>
</tr>
<tr>
<td>Caravale et al. (2005)</td>
<td></td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td>Congenital abnormalities, major neurological signs</td>
</tr>
<tr>
<td>Espy et al. (2002)</td>
<td></td>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td>GA &lt; 28 wks, IVH II, PVL, seizures, chronic lung disease, BPD</td>
</tr>
<tr>
<td>Hunnius (2004)</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>ROP &gt; I</td>
</tr>
<tr>
<td>Kopp and Vaughn (1982)</td>
<td></td>
<td>76</td>
<td></td>
<td></td>
<td></td>
<td>Multiple birth, SGA, motor or sensory handicaps, Bayley MDI &lt; 60 at 2 years</td>
</tr>
<tr>
<td>Landry et al. (1985)</td>
<td>RDS and IVH</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td>Sensory handicap, CP diagnosis, non-IVH-related hydrocephalus</td>
</tr>
<tr>
<td>Lawson and Ruff (2004)</td>
<td></td>
<td>55</td>
<td></td>
<td></td>
<td></td>
<td>Sensory or neurological problems, significant impairment</td>
</tr>
<tr>
<td>Matthews et al. (1996)</td>
<td></td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td>IVH &gt; II</td>
</tr>
<tr>
<td>McGrath et al. (2005)</td>
<td></td>
<td>32</td>
<td>Healthy</td>
<td></td>
<td></td>
<td>IVH &gt; II, congenital malformations, neurosensory deficits</td>
</tr>
<tr>
<td>McGowan et al. (1997)</td>
<td></td>
<td>53</td>
<td>Medical</td>
<td></td>
<td></td>
<td>IVH &gt; II, congenital malformations, neurosensory deficits</td>
</tr>
<tr>
<td>McQuarrie et al. (1999)</td>
<td></td>
<td>32</td>
<td>Neurological</td>
<td></td>
<td></td>
<td>Congenital, neurological or physical abnormalities</td>
</tr>
<tr>
<td>Pridham et al. (2000)</td>
<td></td>
<td>16</td>
<td>BPD</td>
<td></td>
<td></td>
<td>Congenital anomalies or syndromes, blindness</td>
</tr>
<tr>
<td>Ross et al. (1992)</td>
<td></td>
<td>30</td>
<td>IVH grade I–II</td>
<td></td>
<td></td>
<td>SGA, IVH, PVL, ROP, neonatal convulsions, Konner’s medical risk index &gt; 3</td>
</tr>
<tr>
<td>Rose et al. (1988)</td>
<td></td>
<td>50</td>
<td></td>
<td></td>
<td></td>
<td>Severe visual, auditory or neurological impairment, congenital anomalies</td>
</tr>
<tr>
<td>Rose et al. (1991)</td>
<td></td>
<td>63</td>
<td></td>
<td></td>
<td></td>
<td>Congenital abnormalities, abnormal cerebral ultrasound, CP, blindness, deafness, IQ ≤ 90</td>
</tr>
<tr>
<td>Rose et al. (2001, 2002a,b)</td>
<td></td>
<td>59</td>
<td></td>
<td></td>
<td></td>
<td>Multiple birth, SGA, neurological insult, genetic and chromosomal abnormalities, infection, disease</td>
</tr>
<tr>
<td>Ruff et al. (1990)</td>
<td></td>
<td>63</td>
<td></td>
<td></td>
<td></td>
<td>Congenital abnormalities</td>
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<tr>
<td>Sigman et al. (1977)</td>
<td></td>
<td>28</td>
<td></td>
<td></td>
<td></td>
<td>Multiple birth, IVH &gt; II, hydrocephalus</td>
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<tr>
<td>Sigman and Beckwith (1980); Sigman et al. (1986); Cohen and Parmelee (1983)</td>
<td></td>
<td>122</td>
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<td>Strogonova et al. (2005, 2006a, 2006b)</td>
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<td>19</td>
<td></td>
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<tr>
<td>Sun (2003)</td>
<td></td>
<td>37</td>
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<tr>
<td>Thanh Tu et al. (2007)</td>
<td></td>
<td>103</td>
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<td>Vicari et al. (2004)</td>
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<td>19</td>
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<td>Wilcox et al. (1996)</td>
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<td>18</td>
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<tr>
<td>Woodward et al. (2005)</td>
<td></td>
<td>92</td>
<td></td>
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<tr>
<td>Wijnoek et al. (1998, 2003)</td>
<td></td>
<td>66</td>
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</tbody>
</table>

**GA:** gestational age in weeks, **BW:** birth weight in grams, **CNS:** central nervous system, **PVE/L:** periventricular echocengecity/leukomalacia, **BPD:** bronchopulmarony dysplasia, **RDS:** respiratory distress syndrome, **IVH:** intraventricular hemorrhage, **ROP:** retinopathy of prematurity, **CP:** cerebral paresis, **SGA:** small for gestational age.
to find differences in looking durations in infants born preterm and infants born at term between 2 and 6 months of age during the encoding phase of a VExP paradigm (Wilcox, Nadel, & Rosser, 1996), or during habituation and novelty preference (Bonin et al., 1998), studies with medically at risk samples (i.e. suffering perinatal medical complications) found infants born preterm to look longer than infants born at term, at the expected due date (Sigman, Kopp, Littman, & Parmelee, 1977), and at 5, 7 and 12 months of age (Rose et al., 2001). Keeping the development-
The literature on sustained attention during free play in infants born preterm shows some contradictory results. Whereas some researchers found infants born preterm to show less sustained attention and more off-task behavior than infants born at term (Rose et al., 2001, 1988; Sun, 2003; Thanh Tu et al., 2007), others found no differences (Pridham, Becker, & Brown, 2000; Rose et al., 1991), or even found longer periods of sustained attention in infants born preterm than infants born at term during free play (Ruff, Lawson, Parrinello, & Weissberg, 1990). Sun (2003), for example, showed that 8-month-old infants born preterm show shorter periods of sustained attention and more off-task behavior during free play with several toys, than infants born at term. A trend of lower quality of sustained attention in 8-month-old infants born preterm, compared to infants born at term, was also found by Thanh Tu et al. (2007). Pridham et al. (2000), on the other hand, found no differences in sustained attention between 8-month-old infants born preterm and infants born at term during free play. Moreover, a longitudinal study by Ruff et al. (1990), conducted at 1, 2 and 3.5 years of age, revealed longer periods of sustained attention in infants born preterm than infants born at term at 2 years, but only when developmental scores were above 80. These differences in results are difficult to explain. Although Ruff et al. (1990) speculate that longer periods of sustained attention in children born preterm may be caused by a tendency to be less active and more compliant, making it easier for these children to focus and maintain attention, this hypothesis cannot explain why other studies report less sustained attention in children born preterm.

Studies investigating off-task behavior during novelty preference paradigms also show inconsistent results. For instance, although Rose and co-workers showed that infants born preterm spent more time off target than infants born at term at 7 months (Rose et al., 1988), these differences disappeared at 12 months (Rose et al., 1991). In another longitudinal study, Rose and co-workers found opposite results, when infants born preterm showed more off-task behavior at 12 months of age, but not at 5 or 7 months of age, in a paired comparison task (Rose et al., 2001).

When infants become toddlers, and the arousal system becomes more and more under the control of the executive control system, researchers report more matching results, indicating shorter periods of sustained attention in children born preterm than in children born at term (Caravale, Tozzi, Albino, & Vicari, 2005; McGrath et al., 2005; Vicari, Caravale, Carlesimo, Casadei, & Allemand, 2004). For example, McGrath et al. (2005) demonstrated that high-risk children born preterm were less attentive than children born at term during a problem solving task at 4 years of age (not corrected for prematurity). This finding is consistent with that of Vicari et al. (2004) and Caravale et al. (2005),
who found that even low-risk children born preterm showed shorter periods of sustained attention, during a structured barrage task, than children born at term, at 3 to 4 years (not corrected for prematurity).

In sum, studies investigating sustained attention during infancy show some contradicting results, suggesting that problems with sustaining attention are not always evident in infants born preterm during infancy. However, the few studies investigating sustained attention during the preschool years are more congruent, suggesting that problems with sustained attention become more visible in children born preterm with increasing age, regardless of their risk status.

2.1.3. The executive control system

Researchers investigating executive attention skills in infants born preterm also report some contradictory findings (Matthews, Ellis, & Nelson, 1996; Ross et al., 1992; Sun, 2003). Matthews et al. (1996) found, for example, that 6- to 14-month-old, low-risk infants born preterm outperformed infants born at term at a reaching as well as a non-reaching version of the AB task, suggesting an advantage of extrauterine experience of children born preterm in comparison to children born at term. However, the results of a study by Ross et al. (1992) indicated poorer AB performance in 10-month-old infants born preterm compared to infants born at term. Similar findings were reported in a more recent study, which demonstrated that 8-month-old infants born preterm perform poorer on both inhibitory aspects and working memory aspects of the AB task than infants born at term (Sun, 2003). In this study, infants born preterm had more trouble finding hidden objects, and were more inclined to reach toward the incorrect location after the side of hiding was changed. Also, infants born preterm were distracted more often by the cup that covered the toy, making them fail to retrieve the goal object (Sun, 2003). These differences in results can be explained by the fact that infants in the study by Matthews et al. (1996) were part of a healthy low-risk sample, in contrast to the studies by Ross et al. (1992) and Sun (2003), in which infants born preterm formed a more heterogeneous group differing in degrees of medical risk.

The few studies that have investigated executive attention during the preschool years are more congruent and show some surprising patterns of performance in children born preterm (Espy et al., 2002; Woodward, Edgin, Thompson, & Inder, 2005). Using two delayed-response-type tasks, similar in format to the AB task, Espy et al. (2002) compared 2- to 3-year-old, low-risk children born preterm with full-term peers. Although children born preterm performed comparably on the Spatial Reversal task to children born at term, children born preterm chose a previously un-rewarded location more often than children born at term in the Delayed Alternation task, instead of the more common and expected perseverative error of reaching toward a previously rewarded location. Espy et al. (2002) argue that this specific response bias of persistently choosing a maladaptive and unrewarding strategy might be viewed as an early indication of the frequently observed executive dysfunction at school-age in children born preterm. This unique pattern of errors was also found in a study by Woodward et al. (2005). During an age appropriate AB task at 2 years of age, children born preterm showed overall poorer performance than children born at term. Also, children born preterm were nearly twice as likely to make non-perseverative errors than children born at term, whereas children born at term tended to make the anticipated perseverative error.

In sum, taking into account the mixed results from infant studies and the more congruent results from preschool studies using delayed-response tasks, it seems that problems with executive attention become more apparent with increasing age, even in low-risk infants born preterm. Surprisingly, however, preschoolers born preterm do not seem to have problems with inhibition of a previously rewarded response, but rather with inhibiting attention to irrelevant task-features or distracters (such as the cup that covered the toy or other hiding wells). This pattern of errors suggests difficulties with higher-level control of sustained attention, and already can become visible in infancy.

2.2. Risk and protective factors in early attention development

In developmental psychology it is widely recognized that infant development is influenced by – the interaction between – biological factors (such as perinatal factors, postural control, gender and temperament), and environmental factors (such as socioeconomic factors and parental interactive behaviors) (Sameroff & MacKenzie, 2003). In the following section we will examine the biological and environmental factors that may influence early attention development within the preterm population. Although many of these factors are interrelated – perinatal factors in particular (e.g. infants who are born at a shorter gestational age, have lower birth weights) – the influence of each factor is discussed separately.
2.2.1. Biological factors

2.2.1.1. Gestational age. There has been some debate on the issue whether premature birth in itself has a negative influence on development (Sesma & Georgieff, 2003). In fact, some results from studies comparing infants born preterm with infants born at term suggest an advantage of preterm birth in attentional abilities, especially when age was corrected for prematurity. For example, studies investigating disengagement showed that infants born preterm initially shifted faster than full-term infants, although this difference disappeared at older ages (Butcher, 2000; Butcher et al., 2002; Hunnius, 2004). An advantage of additional experience in infants born preterm was also suggested by Matthews et al. (1996) who found better AB performance in infants born preterm than in infants born at term. Studies investigating the predictive value of GA within the preterm population show mixed results. Although Rose et al. (2002) failed to find a relationship between GA and off-task behavior during infancy, studies during preschool age did link shorter GA to poorer attention skills in infants born preterm. That is, preschoolers, who were born at a shorter GA tended to perform poorer on the AB task at 2 years (Woodward et al., 2005), and to show less sustained attention during problem solving at 4 years than preschoolers born after longer GA, but still before their expected birth date (McGrath et al., 2005), suggesting that birth at a less mature state can have detrimental effects on attention development. In an effort to disentangle the effects of maturation of the central nervous system from the time of conception versus the effects of exposure to extrauterine environmental stimulation, Sun (2003) not only compared infants born preterm with infants born at term of the same corrected age (8 months), but also with infants born at term of the same chronological age (10–11 months). Her findings that infants born preterm performed more poorly than infants born at term of both ages on all measures of sustained and executive attention, suggest that the effects of immaturity are greater than the effects of additional extrauterine experience. Comparison within the preterm group, however, revealed no significant difference between infants born before or after 28 weeks of gestation, suggesting that GA has little influence on attention development over the effects of prematurity per se, at least not at this early age.

In conclusion, it seems that, although premature birth may give infants an early advantage in some domains due to greater experience in the extrauterine environment, this advantage is probably short-term and the negative effects of immaturity are greater than the positive effects of extrauterine exposure. The association between shorter GA and poorer attention skills in preschoolers in particular, may suggest that children born preterm grow into their attention deficits. However, whether these negative effects of shorter GA on attention skills are due to immaturity or to other related differences (such as differences in level of stress or pain) are not clear. For example, a more premature birth is likely to be accompanied by more neonatal pain-related stress, because children born at a shorter GA often need more medical interventions and skin breaking procedures.

2.2.1.2. Birth weight. Although Rose et al. (1988) found that lower BW in 7-month-old infants born preterm was related to poorer attention abilities, the predictive value of BW was not confirmed by the majority of studies reviewed here (Bonin et al., 1998; McGrath et al., 2005; Pridham et al., 2000; Rose et al., 2002a; Sun, 2003; Woodward et al., 2005). BW did not correlate significantly with visual orienting at 5, 7 or 12 months (Bonin et al., 1998; Rose et al., 2002a, 2002b), sustained attention during free play at 8 months (Pridham et al., 2000), AB performance at 2 years of age (Woodward et al., 2005), or sustained attention during problem solving at 4 years (McGrath et al., 2005). Comparisons between different BW groups of infants born preterm also failed to reveal any differences. Neither looking duration between 2 and 6 months of age differ between VLBW and LBW infants born preterm (Bonin et al., 1998), nor did sustained attention during free play or AB performance at 8 months differ between ELBW and VLBW infants born preterm (Sun, 2003). Nevertheless, Sun (2003) did report that the difference in AB performance between ELBW infants born preterm and infants born at term was greater (and significant) than the difference between VLBW infants born preterm and infants born at term. Moreover, although the difference between ELBW and VLBW infants was not significant, the results were in the expected direction. The failure to reach statistical significance is probably due to small sample sizes. These results suggest that lower BW has a negative gradual effect on executive attention. On the other hand, it is possible that these BW-groups differed in other aspects as well (e.g. medical complications).

An issue that is related to BW is intrauterine growth retardation. Although many infants born preterm have appropriate weight for gestational age, a potential risk factor in infants born preterm is intrauterine growth retardation, usually resulting in being small for gestational age and having a subnormal head circumference (Gibson, Carney, & Wales, 2006; Peterson, Taylor, Minich, Klein, & Hack, 2006; Rugolo, 2005). While smaller head circumference was predictive of less mature attention skills during visual recognition at 7 months (Rose et al., 1988), no relationship was found...
between being small for gestational age and attention skills during a VExP paradigm between 5 and 10 months (Rose et al., 2002a), or between intrauterine growth retardation and AB performance at 2 years (Woodward et al., 2005).

In conclusion, despite some associations with BW and head circumference, the evidence for the predictive value of BW and related indices of growth for early attention development has not been very strong.

2.2.1.3. Medical risk. Several studies have investigated the association between the presence and/or severity of medical complications during the perinatal period and attention skills in infants born preterm. The predictive value of medical complications is usually investigated by using summary scores of neonatal risk, or by determining the relationship with more specific risk factors or medical complications, such as bronchopulmonary dysplasia (BPD) and intraventricular hemorrhage (IVH), either by calculating correlations or by assigning infants born preterm to subgroups based on the presence or severity of medical complications.

The predictive value of summary risk scores for early attention development has not been very strong. Although Rose et al. (2001) found that more medical complications were associated with less optimal attention at 5 months, this relationship lost statistical significance at 7 and 12 months. Summary risk scores also showed no relationship to inattentiveness during the first year of life (Rose et al., 2002a), AB performance at 2 years (Woodward et al., 2005), or sustained attention during problem solving at 4 years (McGrath et al., 2005). However, Sun (2003) reported that, although infants born preterm with high medical risk scores did not differ significantly from infants born preterm with low medical risk scores on sustained attention and AB performance measures at 8 months, the difference in AB performance between high medical risk infants born preterm and infants born at term was greater (and significant) than low-risk infants born preterm and infants born at term. Taking into account that the difference in AB performance between low risk and high-risk infants was in the expected direction, and that these groups had small sample sizes, these results suggest that medical risk has a gradual effect on the development of executive attention. However, since infants with lower BW are more prone to medical complications (Aylward, 2002a, 2002b, 2005), it is possible that these groups based on medical risk consisted of roughly the same children as the BW-groups, mentioned earlier.

The results regarding the predictive value of more specific medical complications are mixed as well. The detrimental effects of perinatal brain injury on attention development has been confirmed by Landry et al. (1985), who showed that infants born preterm with IVH displayed longer looks during habituation than infants born preterm without IVH. Ross et al. (1992), however, failed to find any differences in AB performance at 10 months between infants born preterm with or without IVH. Other researchers also did not find significant associations between IVH and inattentiveness in the first year of life (Rose et al., 2002), or between severity of IVH (grade III or IV) and AB performance at 2 years (Woodward et al., 2005). Butcher and colleagues (Butcher, 2000; Butcher et al., 2002) also failed to find a relationship between a transient form of periventricular leukomalacia (PVL), another perinatal brain injury often seen in infants born preterm, and disengagement or inhibition of return during the first 26 weeks of life. However, Woodward et al. (2005) found that AB performance at 2 years was related to white matter injury at term, which is usually the result of a perinatal insult (e.g. anoxia), in various brain areas (such as the DLPC). Poorer AB performance at 2 years was also related to increasing volumes of cerebrospinal fluid.

The harmful effects of lung disease were confirmed by the finding that infants who required more oxygen or ventilation assistance had longer look durations, lower shift rate and longer pauses at 5 and 7 months, although not at 12 months (Rose et al., 2001, 2002a). However, neither the presence of respiratory distress syndrome (RDS) was significantly associated with inattentiveness during the first year of life (Rose et al., 2002a), nor was the presence of BPD associated with AB performance at 2 years (Woodward et al., 2005).

Other neonatal risk factors, which are related to medical complications, have been found to be associated with attention performance in infants born preterm. Longer hospital stay, and lower 1-min and 5-min Apgar scores were found to be related to longer looks and lower shift rates in 5- to 7-month-old infants born preterm (Rose et al., 1988, 2001, 2002a). Furthermore, neonatal pain-related stress, indexed by the number of skin-breaking procedures from birth to term, was associated with poorer sustained attention in 8-month-old infants born preterm. However, although early life stress is associated with future elevated cortisol levels, no relationship between cortisol level at 8 months and sustained attention was found in the same study (Thanh Tu et al., 2007). Also, children whose mothers had fever and children who suffered from sepsis at the time of delivery performed worse on the AB task at 2 years of age (Woodward et al., 2005). The relationship between maternal fever and outcome was mediated by the level of white matter injury in the brain, as measured by MRI at term, but the relationship between infant sepsis and outcome persisted after white matter injury was controlled for (Woodward et al., 2005).
In conclusion, despite some mixed results, the presence and severity of medical complications seem to have a negative influence on attention development. However, as we stated earlier, since GA, BW and severity of medical complications are interrelated, it is difficult to come to any conclusions about the relative contribution of any of these to attention development. In fact, the reported results from Sun (2003) suggest that the influence of GA, BW and medical risk is not strong enough within the preterm population to add to the effect of prematurity in itself. An attempt to disentangle these neonatal risk factors has been made by McGrath et al. (2005), who investigated sustained attention during problem solving at 4 years in four subgroups of infants born preterm and a full-term control group. Infants born preterm were assigned to a healthy (HPT), medical (MPT), neurological (NPT) and small for gestational age (SGA) group, based on the absence or presence and severity of specific medical complications. They found that infants born at term showed more sustained attention than infants born preterm in the medical and neurological groups, but not the healthy or SGA groups, suggesting that medical complications, but not GA or BW, are important predictors for sustained attention at 4 years.

2.2.1.4. Postural control. Adequate postural control in sitting and head control is necessary for reaching behaviors, and thus influences the ability to explore objects. Since many infants born preterm show problems in the regulation of muscle tone, early postural control is a potential predictor of attention development in infants born preterm (Wijnroks & van Veldhoven, 2003). In fact, individual differences in postural control have been shown to be related to subsequent attention behavior in infants born preterm. Infants born preterm with clear signs of hyperextension and elbow extension at 6 months showed more off-task behavior (i.e. inattention) during two problem solving tasks than infants born preterm with adequate postural control, at 24 months, but not at 18 months (Wijnroks & van Veldhoven, 2003).

2.2.1.5. Gender. Since mortality and morbidity in infants born preterm is higher in boys than in girls, and male gender is associated with a heightened risk for developmental delay in infants born preterm (Elsmen, Hansen Pupp, & Hellstrom-Westas, 2004; Salt & Redshaw, 2006; Stevenson et al., 2000), gender is a potential predictor for early attention development as well. The results concerning the predictive value of gender are somewhat mixed. Although gender was not related to sustained attention during free play at 8 months (Kopp & Vaughn, 1982; Pridham et al., 2000; Thanh Tu et al., 2007), or AB performance at 2 years (Woodward et al., 2005), boys showed poorer sustained attention than girls during problem solving at 4 years (McGrath et al., 2005).

2.2.1.6. Temperament. Attention abilities are thought to be related to temperamental aspects as well. Temperament has been defined as constitutionally based individual differences in emotional, motor, and attentional reactivity and self-regulation. It has been proposed that attentional efficiency plays an important role in successful self-regulation (Rueda, Posner, & Rothbart, 2004b; Ruff & Rothbart, 1996). Infants born preterm are often described by clinicians and parents as ‘more difficult’ and ‘less responsive’, suggesting that infants born preterm have problems with self-regulation. Hence, early parental report of infant temperament, and self-regulation in particular, may be a valuable predictor of attention development in infants born preterm. Nevertheless, the only study in this review that examined the predictive value of temperament shows that responsiveness to care, which is considered to reflect self-regulatory abilities, was not related to sustained attention at 8 months (Pridham et al., 2000).

2.2.2. Environmental factors

Since environmental factors, such as maternal IQ, educational level and socioeconomic status (SES) of the parent(s), quality of the home environment (measured with the HOME) (Bacharach & Baumeister, 1998), maternal knowledge of child development and maternal coping (Veddovi, Gibson, Kenny, Bowen, & Starte, 2004) have been shown to influence cognitive, language and behavioral development in infants born preterm, their predictive value for early attention development is of great interest to many researchers. It is, however, not always clear what these factors represent. Most of the time they reflect a mixture of genetic factors, level of intellectual stimulation, and the mother’s mental health. Nevertheless, SES appeared to be positively related to sustained attention during problem solving at 4 years (McGrath et al., 2005), however, no relationship was found between maternal level of education or quality of the home environment and sustained attention during free play at 8 months (Pridham et al., 2000). Also no significant relationship was found between SES, maternal level of education or family income, on the one hand, and AB performance at 2 years, on the other (Woodward et al., 2005). Sun (2003) found that maternal psychological wellbeing, but not maternal level of
education or family income, was related to AB performance in 8-month-old infants born preterm and born at term.

An environmental factor that can be observed more directly is the social interaction a parent has with an infant. Research has shown that observed maternal scaffolding during interaction immediately increases the complexity of infant exploratory play and that this effect was even more apparent in medically high-risk infants born preterm than in low-risk infants born preterm and infants born at term (Landry, Chapieskis, & Schmidt, 1986; Landry, Garner, Swank, & Baldwin, 1996). Moreover, maternal interactive behaviors during play have been demonstrated to influence later global cognitive abilities, language skills and behavioral outcomes in both infants born preterm and infants born at term (Assel et al., 2002; Murray & Hornbaker, 1997; Schmidt & Lawson, 2002; Wijnroks, 1998), and these beneficial effects of high quality interactions are even greater for infants born preterm (Landry et al., 1986; Landry, Smith, Swank, Assel, & Vellet, 2001; Poehlmann & Fiese, 2001; Smith et al., 1996). The few studies investigating the influence of maternal interactive behaviors on early attention in infants born preterm show some different results (Pridham et al., 2000; Thanh Tu et al., 2007; Wijnroks, 1998). The effects of maternal behaviors were demonstrated in a study by Pridham et al. (2000), who found that 8-month-old infants born preterm of mothers, who more often used attention redirecting behaviors (i.e. directing of attention to another object than the one already attended to by the infant), showed less sustained attention when playing alone. The buffering effect of maternal behavior on sustained attention in 8-month-old infants born preterm was also demonstrated by Thanh Tu et al. (2007), who found that a higher quality of maternal interactive behaviors was related to better sustained attention, in mothers who experience low parenting stress but not in mothers who experience high parenting stress. Wijnroks (1998) found, however, that quality of maternal interactive behaviors, such as attention redirecting behaviors, in the first year of life was not predictive of sustained attention in the second year of life in infants born preterm. Surprisingly, no studies were found investigating the influence of maternal behaviors on the development of orienting of attention or executive attention in infants and preschool children born preterm.

2.3. Early attention development as predictor of later attentional, global cognitive and behavioral functioning

In the beginning of this paper we discussed the importance of attention processes for subsequent development. When attention does play this important role in development we would expect early attention to be a powerful predictor of future functioning. The few studies that have investigated the predictive value of early attention development indicate that individual differences in early orienting of attention and sustained attention are indeed important predictors of later attentional, as well as cognitive and behavioral functioning (Cohen & Parmelee, 1983; Kopp & Vaughn, 1982; Lawson & Ruff, 2004; Ruff et al., 1990; Sigman & Beckwith, 1980; Sigman, Cohen, Beckwith, & Parmelee, 1986).

Orienting of attention in infants born preterm has been shown to be modestly stable over the first year of life (Rose et al., 2001, 2002a). For example, Rose et al. (2001) showed that individual differences in looking duration and shift rate were modestly stable between 5 and 7 months, and between 7 and 12 months of age (Rose et al., 2001). The same was found for individual differences in the frequency of anticipatory eye movements from 5 to 7 months, and from 7 to 12 months of age (Rose et al., 2002a). The predictive value of early orienting of attention for later global cognitive functioning was demonstrated in a study by Sigman and Cohen and co-workers, who demonstrated that infants born preterm who displayed longer looks at 40 weeks gestational age (i.e. the expected due date) received lower developmental scores at 18 and 25 months of age (Sigman & Beckwith, 1980), and lower intelligence scores at 5 years (Cohen & Parmelee, 1983), and at 8 years (Sigman et al., 1986). So, surprisingly, even though the developmental trend of looking duration (Colombo, 2001, 2002) might suggest that longer looking during this period in life is a sign of initial higher alertness, these results suggest that longer looking at the expected due date can be considered a risk factor for subsequent developmental delay.

With regard to the stability of sustained attention, Ruff et al. (1990) found that sustained attention in 1-year-old infants born preterm was predictive of sustained attention at 3,5 years, but not 2 years. Lawson and Ruff (2004) found that sustained attention during free play in 7-month-old infants born preterm was predictive of sustained attention at 2 years, but not 3 years. Additionally, they found sustained attention at 7-months to be predictive of behavioral problems (i.e. hyperactivity and impulsivity) at 4 to 5 years, and global cognitive abilities at 2, 3 and 4 to 5 years. The predictive value of early sustained attention for later global cognitive abilities was also demonstrated by Kopp and Vaughn (1982),
who found that boys, but not girls, born preterm who showed more sustained attention during exploratory manipulation at 8 months had higher developmental scores at 2 years.

In sum, individual differences in early orienting of attention show modest stability during the first year of life and are predictive of later global cognitive development and intelligence scores in children born preterm. In addition, individual differences in sustained attention show stability during infancy and the preschool years and are predictive of later global cognitive and behavioral functioning in children born preterm. Unfortunately, there are no studies, to our knowledge, investigating the stability or predictive value of early executive attention in infants and children born preterm.

3. Discussion

The aim of this review was to (1) identify differences in attention development during infancy and the preschool years between children born preterm and children born at term, (2) distinguish important environmental and biological predictors of attention development in children born preterm, and (3) examine the predictive value of early attention development for later functioning in children born preterm.

First, the results described in this review indicate that infants born preterm show less mature visual orienting of attention, less sustained attention and have more trouble with executive attention when compared to infants born at term. Although less efficient attention may not always be evident during infancy, and infants born preterm may even show some initial superior attentional functioning, problems with attention seem to become more apparent as infants born preterm grow into toddlers. Studies investigating executive attention also suggest that infants born preterm have particular problems with the inhibition of potential distracters during executive attention tasks, instead of the expected inhibition of a prepotent response. This unique pattern of errors suggest that the attention problems of infants and children born preterm are not so much the same as attention problems in other populations, but may well be qualitatively different. Second, the literature also shows that early attention development in children born preterm is influenced by biological factors as well as environmental factors. Although additional extrauterine experience may give infants born preterm an initial advantage, the (im)maturational aspects of preterm birth (and perhaps related factors such as neonatal stress) seem to override these effects in time. While some evidence is more convincing than others, biological factors that have been shown to increase the risk of early attention problems in infants and preschool children born preterm are gestational age, lower BW, more severe medical complications, male gender, and inadequate postural control. Environmental factors that have been found to be associated with attention problems in infants and preschool children born preterm are lower SES, lower maternal psychological wellbeing and maternal attention redirecting behaviors. Third, while there is little information about the stability and predictive value of early executive attention for later functioning, early orienting of attention and sustained attention show stability during the first year and the first 3 years of life, respectively. Moreover, early orienting of attention is related to global cognitive development during preschool-age and intelligence during school age. In addition, sustained attention during infancy is related to cognitive abilities and behavioral problems in children born preterm, during the preschool years.

These findings give rise to several explanations and raise new questions. First, although children born preterm show problems in attention behaviors that are associated with Posner’s three attention networks, the conclusion that all networks are compromised in children born preterm must be handled with care. As Posner has emphasized, the three networks are interactive, leaving open the possibility, for example, that less optimal performance on sustained attention tasks may be caused by an increased influence by the executive control system over the arousal system. Because most studies concentrate on behaviors associated with only one of the attention networks, there is little to no knowledge about the interaction between attention networks, and how dysfunction in one network may result in less optimal development and functioning of the other networks.

Also, there are several explanations for the observed trend of a decline in attentional skills in children who were born preterm. Three explanations – which are not mutually exclusive – focus on developmental processes in children. First, it is suggested that subtle deficits in early infancy cause infants born preterm to have less successful experiences and less opportunity to learn (Aylward, 2005). As a consequence, small initial differences may expand over time. A second possibility is that, as the brain matures and children become more capable of complex cognitive processes, subtle deficits in infants born preterm become more apparent (Sesma & Georgiiff, 2003), sometimes referred to as ‘growing into deficit’ in the neuropsychological literature. A third reason has to do with increasing demands from the
environment when infants become toddlers, requiring more complex skills and challenging preterm born children’s vulnerable abilities (Sesma & Georgieff, 2003). It should be noted, however, that the conclusions in this review are based on comparisons between studies which differ greatly not only in the attention measures they use, but also in sample characteristics (including age of the children). For this reason, two alternative explanations for a decline in attentional skills must be considered. One explanation has to do with differences in birth cohorts. Preterm populations studied, say, 20 years ago (e.g., cohorts studied by Landry et al., 1985 and Rose et al., 1988, 1991) are likely to differ in type and extent of medical complications suffered by the children compared to more recently studied preterm populations, because they were born at a time when treatments and technologies in neonatal intensive care units were less advanced (Aylward, 2002a, 2002b). On the other hand, new medical treatments that have resulted in the increased survival of infants born preterm, may have changed the composition of the preterm population to a more high-risk one, and these treatments may also have detrimental effects on development on their own. Steroid treatment, for example, has been linked to lower attention scores in 8-year-old children, who were born preterm and suffered from BPD (Short et al., 2003). A second alternative explanation for a decline in attentional skills lies in the use of correction for prematurity. In the assessment of premature infants it has become standard practice to correct the child’s age for prematurity, at least for the first 2 years of life (Wilson & Cradock, 2004). Accordingly, the studies in this review that were conducted during the first 2 years of life did correct for prematurity, whereas the majority of studies conducted at later ages did not (see Table 1b, sample characteristics continued). The possibility that the trend of worsening outcome with age is confounded by an age-related change in correction for prematurity should therefore not be discarded. Moreover, closer inspection of differences within the preterm population may uncover other developmental courses, besides a trend of worsening outcome. In a review on cognitive development and brain plasticity in children born preterm, Luciana (2003) refers to three other possible developmental paths observed in animal studies. In the first developmental course, damage is so severe that development is hindered without recovery. In the second, development follows the expected path regardless of evidence of injury. In the third, development may be slowed initially but there seems to recover with increasing age.

In addition, the risk and protective factors that were discussed complicate the subject even more. While associations between early attention development and several biological and environmental factors have been found, relationships were not always strong and results from different studies were mixed. A possible explanation for these incongruent results is that the impact of different factors varies with different forms of attention or becomes visible at different ages. It has been shown, for example, that environmental effects on development become more apparent around 24–36 months of age (Aylward, 2002b). The interaction between biological risk factors and environmental factors makes the issue even more complicated, especially since many children are exposed to both biologic and environmental risk. Environmental influences can temper or aggravate the developmental problems that occur as a result from biologic factors. Although extreme biological events may override moderating environmental influences (Aylward, 2002a, 2002b), infants born preterm with high medical risk may be more susceptible to positive or negative environmental influences than infants born preterm with low medical risk (Landry et al., 1986, 1996). The influence of environmental factors may also be dependent on infant characteristics, such as temperament. A study with 4-month-old infants born at term showed, for example, that highly responsive infants show better attentional performance if parented by mothers who were less actively involved during toy play interactions (Micieli, Whitman, Borkowski, Braungart-Rieker, & Mitchell, 1998). Thus, what seems to be of crucial importance – especially for infants at risk – is the fit between parental interactive styles and infant characteristics.

Although the relationship between temperamental self-regulation and attention development has been discussed briefly, the single study that investigated this relationship found no significant association. The topic, however, is of considerable relevance, since brain-imaging studies have shown that self-regulation is associated with activation of (partly) the same brain structures as executive attention (Rothbart & Posner, 2005; Rueda et al., 2004a; Rueda, Posner, & Rothbart, 2005a). Although some researchers emphasize that attentional functioning influences self regulatory abilities (e.g. attention to a visual stimulus can have a powerful soothing effect) (Rueda et al., 2004a, 2005a), and others stress that problems in attentional control are caused by deficits in self-regulation (Davis & Burns, 2001), it is difficult to say which ability emerges first. Keeping the findings for a similar brain basis in mind, it is probably more likely that self-regulatory and attention abilities develop at roughly the same time, each influencing the development of the other.

It should also be noted that there are potential predictive factors that have not been discussed here. Risk factors that – to our knowledge – have not yet been investigated in relation to early attention development, but have been shown to be predictive of attention performance in school-aged children born preterm, are problems in peripheral sensory
systems (i.e. stereopsis) (Torrioli et al., 2000), and early minor motor difficulties (Jeyaseelan, O’Callaghan, Neulinger, Shum, & Burns, 2005). There is also increasing interest in the consequences of perinatal brain injury in specific brain areas, such as the hippocampus and the caudate nucleus, which have important interconnections to the prefrontal cortex (Abernethy, Cooke, & Foulder-Hughes, 2004; Luciana, 2003).

In conclusion, review of the literature confirms that infants and preschool children who are born preterm show less efficient attention behaviors than infants and preschool children born at term. Furthermore, early individual differences between children born preterm are influenced by biological as well as environmental factors, and are predictive of later attentional, cognitive and behavioral functioning. However, from this review it also becomes clear that some important questions remain insufficiently answered: (1) how stable are individual differences in orienting, sustained and executive attention from infancy until adolescence? (2) Do problems in one attention network influence the functioning and development of other attention networks? (3) Are patterns of change in children born preterm indeed characterized by a decline over time, structural delay, catch-up, or by a combination of these? (4) How does the influence of biologic and environmental factors vary over time and how do these interact? and (5) how do early individual developmental trajectories in attention predict later attentional, cognitive and behavioral functioning? To answer these questions, future follow-up studies should ideally cover the age range from infancy to adolescence, with regular measurements of different attention processes, taking into account several biological and environmental predictors. Repeated measures of environmental factors at different ages are necessary to investigate whether there are periods when infants or children are particularly sensitive for environmental influences. If possible, infants born preterm should be compared to infants born at term of the same corrected age as well as the same chronological age after the second year of life, to rule out effects of age-adjusted scores. However, when elimination of a full-term control group results in larger sample size(s) in preterm (sub)group(s), this may be a serious consideration. Large sample sizes allow one to look more closely at individual differences in developmental trajectories between infants born preterm. Also, we need to be more precise about which neurological processes can lead to later attentional difficulties and how these processes might be mediated by the influence of experience and moderated by specific child characteristics, such as self-regulation. In this review, the neuropsychological model of attention development by Posner and co-workers (Posner & Petersen, 1990; Posner & Raichle, 1994), has proven to be a useful framework to group the vast amount of studies from different backgrounds, investigating visual attention in infants and preschool children born preterm. In fact, more recently, an adult test for the efficiency of the orienting, alerting and executive attention networks, the Attention Network Test (ANT) (Fan, McCandliss, Sommer, Raz, & Posner, 2002) has been adapted to study the development of these networks during childhood (Rueda et al., 2004a), and has been used to study attention in children as young as 4 years of age (Rueda, Rothbart, McCandliss, Saccomanno, & Posner, 2005b). Therefore, Posner’s model of attentional networks provides a useful framework to structure future attention research in a more developmental perspective, especially since it provides a well-established battery of measures for the functioning of the attention networks from childhood into adulthood.

Understanding of the specific attention problems that infants and children born preterm face, and the biological and environmental factors that influence them is crucial for effective intervention. Knowledge on the biological risk factors that make infants born preterm vulnerable to problems in attention can be helpful in the early selection of groups of infants for follow-up programs and intervention. A better understanding of how maternal interactive behaviors interact with infant characteristics is necessary to customize intervention to individual parent–infant dyads. Also, when there is more insight in which aspects of attention are most prone to delay or dysfunction, specific attention trainings can be developed to influence the efficiency of attentional functioning. There has been an encouraging report of an executive attention training in 4-year-old and 6-year-old children, in which the training increased not only attentional functioning (demonstrated by higher attention scores and more adult-like brain activation), but also increased overall IQ (Rueda et al., 2005b).

References


