Development and Psychopathology **27** (2015), 443–457

doi:10.1017/S0954579415000085

Neural plasticity and the development of attention: Intrinsic and extrinsic influences

MARGARET M. SWINGLER, NICOLE B. PERRY, AND SUSAN D. CALKINS
University of North Carolina at Greensboro

Abstract

The development of attention has been strongly linked to the regulation of emotion and behavior and has therefore been of particular interest to researchers aiming to better understand precursors to behavioral maladjustment. In the current paper, we utilize a developmental psychopathology and neural plasticity framework to highlight the importance of both intrinsic (i.e., infant neural functioning) and extrinsic (i.e., caregiver behavior) factors for the development of attentional control across the first year. We begin by highlighting the importance of attention for children's emotion regulation abilities and mental health. We then review the development of attention behavior and underscore the importance of neural development and caregiver behavior for shaping attentional control. Finally, we posit that neural activation associated with the development of the executive attention network may be one mechanism through which maternal caregiving behavior influences the development of infants' attentional control and subsequent emotion regulation abilities known to be influential to childhood psychopathology.

Although the study of attention and its development has a long and rich history (e.g., Colombo, 2001, for a review; Lansink & Richards, 1997; Richards & Casey, 1990), more recent work has focused on the role of early attention skills in the emergence and maintenance of adaptive behavior and functioning in a range of domains. Attention skills are thought to be especially important for the regulation of behavior and emotions in infancy and early childhood (e.g., Posner & Rothbart, 1998; Rothbart, Posner, & Boylan, 1990; Ruff & Rothbart, 1996). Because deficits in early regulation abilities are considered to be central to childhood psychological problems, and thought to partially constrain subsequent development in a variety of domains (Calkins, 2008; Calkins & Fox, 2002; Keenan, 2000), a child's ability to control his or her own experience and expression of negative emotion is critical for adaptive social and emotional functioning. Moreover, the lack of such skills has been implicated as a precursor to the development of both anxiety and antisocial behavior (Calkins & Keane, 2004; Kindt & Van Den Hout, 2001). Thus, basic attentional processes appear to contribute to the development of more sophisticated regulatory processes, such as those involved in the control of emotion, and are implicated in developmental pathways to adaptive and maladaptive functioning throughout life.

Current conceptualizations of child development acknowledge that there are complex interactions among the child's biology, behaviors, and environment (Gottlieb, 1997; Sameroff, 2010; Shonkoff, 2010) that impact developmental pathways. Development in any domain is at least partially dependent on fundamental neurophysiological, behavioral, and social processes, which become elaborated and integrated over time (Calkins, 1994, 2008; Thompson, Lewis, & Calkins, 2008). This biopsychosocial perspective underscores the contribution of underlying biological processes that interact with the child's environment to produce patterns of growth and change influential to the development of important skills critical for adjustment. This is echoed in a developmental psychopathology perspective that advocates an organizational view of development and underscores the importance of investigating multiple factors, or levels of a given factor, in the context of one another rather than in isolation (Cicchetti & Dawson, 2002). From this perspective, there are multiple pathways to maladaptive and adaptive outcomes, and a number of contributors may interact in various ways within different individuals to predict disordered behavior and/or multiple variants of emotional functioning (Cicchetti, 1984, 1993; Cicchetti & Rogosch, 1996; Sroufe & Rutter, 1984). In this paper, we use such a perspective to understand the role that early attention processes may play in developmental pathways to adjustment and maladjustment.

In this paper, we adopt the premise that there are fundamental neural and behavioral attentional processes that grow, interact, and integrate throughout development that provide the basis for the development of attention skills and the emergence of adaptive emotion regulation abilities (Thompson & Goodvin, 2007). However, like others (e.g., Blair, 2002; Calkins, 2011), we view this development as a dynamic process involving transactions between the child and his or her environment. Basic research on human neuroplasticity has identified neurocognitive systems underlying

Address correspondence and reprint requests to: Margaret M. Swingler, University of North Carolina at Greensboro, 248 Stone Building, PO Box 26170, Greensboro, NC 27402; E-mail: mmswingl@uncg.edu.

attention as displaying a great deal of plasticity in early development (e.g., Sanders, Stevens, Coch, & Neville, 2006; Stevens & Neville, 2013). During this period of increased plasticity, interactions with caregiver(s) dominate the infant's social environment, making caregiver behavior a key factor contributing to individual differences in the emergence, maturation, and consolidation of behavioral and neurocognitive systems underlying attentional control and subsequent adjustment or maladjustment (Cicchetti & Dawson, 2002; Luthar, Cicchetti, & Becker, 2000).

Throughout the paper, we utilize a developmental psychopathology and neural plasticity framework to highlight the importance of considering both extrinsic environmental (i.e., caregiver behavior) and intrinsic biological (i.e., infant neural functioning) factors, as well as potential dynamic transactional effects between the two, for the development of attentional control. We believe that using such a perspective and considering development across levels of biology, behavior, and environment provides us with insight into the more proximal developmental mechanisms and processes that influence the early development of attention. A greater understanding of early attentional development may not only help to identify critical points of entry for early intervention and prevention but also increase our understanding of the emergence of later emotion regulation capabilities and lead to advances in the diagnosis, prevention, and possible treatment of increasingly prevalent disorders associated with deficits in the regulation of attention and emotion (Fox & Calkins, 2003).

We begin by highlighting the importance of attentional control for children's behavioral adjustment rooted in the development of emotion regulation abilities. We then review the development of attention behavior and underscore the importance of developing neural systems and caregiver behavior for shaping attentional control. Finally, we posit that the experience-dependent neural plasticity that is characteristic of attention systems in the brain may be one mechanism through which maternal caregiving behavior influences the development of infants' attentional control in the first year and later emotion regulation abilities known to be influential to childhood psychopathology.

Attention Behavior and Emotional Responding

Attentional control has been of particular interest to researchers aiming to better understand precursors to adaptive emotional functioning and behavioral maladjustment because it has been associated with mechanisms for resolving conflict among thoughts, feelings, and behavioral responses (Rueda, Posner, & Rothbart, 2005). For example, the ability to control attention is thought to be one process that allows infants to regulate more biologically based emotional reactivity to produce behavior. Emotion regulation in the first year has been largely described and defined in terms of attentional and motoric control mechanisms that emerge early in development and operate primarily to regulate distress (Posner & Rothbart, 2000; Rothbart & Bates, 1998). Attention orienting skills in particular have been identified as a critical component of early emotion regulation processes, because orienting has the direct effect of amplifying at a neural level the stimuli toward which attention is directed, thus changing the affective experience of the individual (Rothbart, Posner, & Rosicky, 1994).

Given the role attentional processes play in infants' control of arousal and regulation of affective expression, qualitative shifts in attention skills across the first 12 months of life can be seen as fundamental to the qualitative shifts in emotion regulation that are also observed during this period. The period from 3 to 6 months, for example, marks a major transition for infants in which the ability to voluntarily control their own attention, and subsequently their own arousal level, begins to emerge (Calkins, 2004). Rothbart (1981, 1986) found increases in positive affect and decreases in distress in infants this age during episodes of focused attention, providing empirical evidence that control of attention is tied to affective experience during this time period. By the end of the first year, infants are able to employ organized sequences of behavior during emotionally arousing contexts that enable them to disengage, redirect attention, and self-sooth in a flexible manner that suggests that they are responsive to environmental cues and able to adapt their own behavior accordingly (Calkins, 2004). The coincident timing of the emergence of more sophisticated attentional control with more adaptive emotion regulation abilities has been proposed as further evidence of an association between the development of the attention system and emotional functioning in the first year of life (Bell & Calkins, 2012).

Deviations or delays in the development of attentional control and associated regulation likely contribute to maladaptive developmental trajectories associated with poor regulatory abilities. Thus, the importance of regulation of attention and the management of emotional (and nonemotional) arousal for adaptive functioning has been underscored in work examining the etiology of a range of developmental psychopathologies that all include problems with attention as a common symptom (e.g., Rothbart & Posner, 2006). For example, deficits in alerting, attention shifting, and sustaining attention, have been linked to attention-deficit/hyperactivity disorder, with inattentive children showing a decreased ability to maintain an alert state and sustain attention in the absence of valid cues (Casey, Castellanos, Giedd, & Marsh, 1997; Swanson et al., 1991).

Orienting and attention-shifting abilities have been theoretically and empirically linked to anxiety, depression, and mood disorders as well (Derryberry & Rothbart, 1988; Fox, Russo, & Dutton, 2002). Because a tendency to focus and ruminate on negative ideations is a symptom of anxiety and depression (Beck, 1976), one proposed explanation for this link is that individual differences in orienting and attention shifting may be related to the time and effort spent dwelling on negative stimuli (Rothbart & Posner, 2006). In addition, neuroimaging data has shown that cognitive–behavioral therapy,

https://doi.org/10.1017/S0954579415000085 Published online by Cambridge University Press

an effective treatment for depression, resulted in change in neural networks that included areas involved in attention (Cicchetti & Posner, 2005; Goldapple et al., 2004; Mayberg, 2003). Given these direct associations, and that attentional processes have been suggested as a mechanism through which infants and toddlers gain control of arousal and regulate affective expression, a better understanding of the development of attentional control within the first year is critical for advancing our knowledge of the development of emotion regulation and emotional competence thought to underlie later behavioral adjustment (Bronson, 2000; Calkins, 2004).

The Development of Attention Behavior in the First Year

Attention is typically defined as achieving and maintaining an alert state, orienting to sensory events, and controlling thoughts and feelings (Posner & Fan, 2008). The measurement of infant visual attention has a long history as a tool for assessing various aspects of early development and has been shown to be a significant predictor of childhood cognitive functioning and associated outcomes (Colombo, 2002; Posner & Fan, 2008). Early developmental work on infant attention used visual habituation paradigms (i.e. repeated stimulus presentations) and looking duration as the primary measures of attentional control. This body of literature led to the notion that development of attention over the first year was primarily characterized by a linear decrease in the duration of looking, with younger infants (e.g., 3-month-olds) looking for more prolonged periods relative to older infants (e.g., 7-month-olds; Colombo & Mitchell, 1990). However, a comprehensive meta-analysis (Colombo, Harlan, & Mitchell, 1999) of the data on the development of look duration over infancy revealed evidence for three fairly distinct phases of attention development. From birth to 8–10 weeks, look duration increases and is thought to reflect an increase in alertness and attention engagement abilities. During the 3- to 6-month period, look duration declines and is thought to be reflective of more sophisticated information processing leading to shorter durations of attention engagement needed to process a stimulus. From 7 months on, looking duration plateaus or may gradually increase in response to more complex or dynamic stimuli. Thus, maintaining an alert state and orienting to sensory events are the primary components of infants' attentional abilities very early in life, but attentional flexibility and the capacity to control and manipulate attention is evident by the end of the first year (e.g., Rothbart et al., 1994; Ruff & Rothbart, 1996).

Despite clear developmental patterns of looking behavior associated with attention processes, early work also demonstrated individual differences in duration of looking that were relatively stable within an individual across testing occasions and associated with later attention performance (Colombo, Mitchell, O'Brien, & Horowitz, 1987). For instance, infants with longer looking times tended to perform more poorly than their shorter looking peers on visual recognition and memory tasks, especially when the amount of exposure to stimuli was limited (e.g., Colombo, Mitchell, Coldren, & Freeseman, 1991). Longer looking times have also been associated with delays in the ability to disengage and shift visual attention, suggesting a perseveration of attention beyond what is necessary for stimulus processing. This has led to the hypothesis that individual differences in attention measured by looking duration reflect the speed of information processing, which has been shown in work from a number of different groups to be related to multiple aspects of later functioning (for a review, see Colombo, Kapa, & Curtindale, 2010), including emotion regulation (Diaz & Bell, 2011). Essentially, shorter looking times may reflect better attention and information-processing abilities, which allows infants to receive accurate and important information from their surroundings more quickly. The result of this is a greater potential for learning from the visual environment and responding flexibly and efficiently to environmental demands (Ruff & Rothbart, 1996).

Following the initial work on looking duration as an indicator of attention functioning, a major contribution to the study of attention in development came with the application of cognitive neuroscience methods to demonstrate that infant looking is not a unidimensional behavior, but rather represents a variety of attentional states and components that work together to influence looking behavior. These components include the processes of orienting and engaging attention, disengaging attention, shifting attention, and sustaining attention (also called endogenous attention). A number of studies found that infants' look durations very early in development are directly related to these specific components of visual attention and may be an early indicator of their development. For example, look duration during a familiarization episode was significantly correlated with later attention disengagement in 3- and 4-month-olds (Frick, Colombo, & Saxon, 1999), and attention disengagement, distribution, and shifting in 5- to 9-month-olds (Jankowski & Rose, 1997). Developmental work has shown that these components of attention typically emerge sequentially in development with orienting and engaging attention emerging early and disengaging, shifting, and sustaining attention emerging later in the first year. In addition, these behaviors are exhibited and seem to serve a common purpose for the infant across cognition and emotion contexts, providing support for the general involvement of attention in regulatory processes across a variety of environmental situations and demands (e.g., Johnson, Posner, & Rothbart, 1991).

The elaboration of this basic developmental work in the last 20 years has supported the existence of three brain networks that contribute to attention and underlie the emergence of these behaviors: the alerting, orienting, and executive attention network(s) (Posner & Dehaene, 1994; Posner & Petersen, 1990). Alerting is the most basic aspect of attention and describes the state of wakefulness and arousal of an organism that is present from birth; the emergence of the alerting network prior to 3 months of age is thought to underlie the initial increase in infants' looking behavior (Colombo et al., 1999). The orienting network is involved in the selection of information from sensory input and allows the infant to begin to disengage fixation and voluntarily shift visual attention (Posner & Peterson, 1990). The orienting network is functionally mature between 3 and 6 months and is thought to underlie the decline in looking that occurs in the middle of the first year (Colombo, 2001; Courage, Reynolds, & Richards, 2006). Executive attention involves mechanisms for resolving conflict among both internal and external information, including conflict among thoughts, feelings, and behavioral responses (Rueda, Posner, et al., 2005). This conflict resolution is necessary for the volitional and more controlled aspects of the attentional system that are reflected in the plateau in looking at the end of the first year, and theorized to underlie the downstream development of emotion regulation and executive functions (Berger, Tzur, & Posner, 2006; Cuevas & Bell, 2014). Its central role in multiple aspects of cognitive and emotional functioning has made executive attention the focus of much developmental and adult work that reveals that one function of the executive attention network in the brain is to monitor and resolve conflict at the neural level using dynamic coordination of promotion and suppression of activation in various brain areas that are central to regulatory efforts across cognition and emotion domains (Berger et al., 2006; Rothbart et al., 1994; Rothbart, Sheese, & Posner, 2007).

Because the early emergence of more sophisticated regulatory strategies is heavily reliant on the development of the executive attention network during the latter half of the first year of life (Fox & Calkins, 2003; Grolnick, Bridges, & Connell, 1996; Kopp, 2002; Silk, Shaw, Skuban, Oland, & Kovacs, 2006), delays or disruptions in the development of the executive attention network may be one source of individual differences in the development of effective emotion regulation and may result in elevated risk for developing early psychopathology such as internalizing and externalizing behavior problems (e.g., Calkins, 1994, 2010; Calkins & Keane, 2004). Thus, individual differences or disruptions in the development of the executive attention network are likely to have a cascade effect on development in associated cognitive and emotional domains that rely heavily on attention. These differences may arise as a result of biological factors within the child or because of variations in environmental input during the period of rapid development of this network in the first year. Understanding the influence of each of these factors as well as potential variations in their dynamic effect on one another within an individual can provide useful information for understanding individual patterns of adaptation and maladaptation.

Extrinsic and Intrinsic Influences on Attention Development

A developmental psychopathology framework necessitates examination of both intrinsic and extrinsic factors to better understand the development of regulatory processes, including attentional control (Calkins, 1994; Fox & Calkins, 2003). For the purposes of this paper, we use the term intrinsic to mean those individual differences that are biologically based (e.g., Calkins, 1994; Fox, 1994; Fox & Calkins, 2003; Fox, Henderson, & Marshall, 2001), and we focus on underlying neural systems that support and are engaged in processes of attention. Extrinsic factors are environmental (e.g., Calkins, 1994; Fox & Calkins, 2003), and because the most salient environment to an infant is the caregiving environment, we limit our discussion to the manner in which caregivers shape and socialize infants' development through patterns of caregiving behavior.

Although we consider these two factors independently in the following sections, we adopt an integrative approach to the study of the development of attention by underscoring the joint contribution of caregiving and neurophysiological processes related to attentional control. Infants and children bring with them strong biological characteristics that underlie their attentional development and are likely present from birth (e.g., Bell et al., 2008; Posner, Rothbart, Sheese, & Tang, 2007; Rueda, Rothbart, McCandliss, Saccamanno, & Posner, 2005). However, these biological underpinnings, including the neural systems underlying attention, are thought to be at least partially modified by environmental input (Bakermans-Kranenburg, van IJzendoorn, Pijlman, Mesman, & Juffer, 2008; Sheese, Voelker, Rothbart, & Posner, 2007; Stevens, Sanders, & Neville, 2006). Thus, considering the integration between intrinsic and extrinsic factors known to influence the development of attention may be more informative than considering each in isolation and may advance our knowledge regarding the plasticity of neurophysiological processes underlying the development of attentional control.

Intrinsic neural systems

The emergence of the alerting, orienting, and executive attention systems in the first year is strongly associated with intrinsic neurophysiological processes. These processes underlie the connectivity of neural circuitry thought to be implicated in the growth and change of attentional abilities. Each of these networks is composed of a different set of brain structures and exhibits a unique developmental trajectory paralleling the emergence of associated attention behavior reviewed earlier (Colombo & Cheatham, 2006; Posner & Fan, 2008). Alerting attention behaviors are associated with the locus coruleus of the pons and right frontal and parietal cortex, while orienting behavior is associated with areas of the frontal eye fields, inferior and superior parietal lobe, and the superior colliculus, a midbrain structure involved in control of gaze movements. The volitional attentional control that defines executive attention is associated with activation of a neural network including the anterior cingulate cortex (ACC) in the medial frontal lobe, lateral frontal and prefrontal cortex, and basal ganglia, which help to start and control movement (Posner & Fan, 2008).

There is some evidence that from very early in development there is at least rudimentary overlap in the functional connectivity of these networks, although activation between brain regions comprising these networks becomes increasingly coordinated during the latter half of the first year with significant development continuing into early childhood (Berger et al., 2006; Posner, Rothbart, Sheese, & Voelker, 2012). Work using functional magnetic resonance imaging functional connectivity (i.e., measurement of synchronization in activity from distinct areas) during a resting state has revealed that in neonates, parietal areas associated with the orienting network exhibit strong connectivity to the lateral and medial frontal areas associated with the executive attention network (Posner et al., 2012). By 2 years of age, the ACC exhibits strong connectivity to both the parietal and frontal areas associated with alerting, orienting, and executive attention (Gao et al., 2009). Thus, although the potential for coordination among brain areas comprising these networks seems to be present early, stronger and more specific connections continue to emerge and strengthen with development and experience.

Neural connections within the executive attention network specifically have been implicated as the most critical for supporting developing regulatory abilities and have therefore been the focus of much theoretical and empirical work (Posner & Rothbart, 1998, 2009; Rothbart et al., 2007). Methodological limitations make examining the development of a *network* of brain areas difficult, especially in infancy. Thus, researchers have begun to focus on specific areas of the brain involved in the development of more sophisticated attentional control. A consistent finding across work utilizing developmental and adult populations is that activity of the ACC and prefrontal cortex is preferentially active in tasks that involve executive attention (Posner & Fan, 2008).

A number of researchers have argued that the ACC and associated areas of the midfrontal cortex are central to the development of the executive attention network because they function to monitor, regulate, and resolve conflicting information from other neural networks (e.g., Botwinick, Braver, Barch, Carter, & Cohen, 2001). Much empirical data from adult work has supported this idea and revealed that a core set of functions subsumed by the ACC facilitate coordination of an integrated network of neural areas that work together in executive attention tasks (Botwinick et al., 2001; Bush, Luu, & Posner, 2000). The ACC seems to be particularly important because it serves as a sort of “relay station” coordinating input and output from multiple areas involved in the control of both cognition and emotion (Posner et al., 2007). Neural activity measured at the midline of the frontal lobe is thought to reflect activity of the ACC, and is consistently shown to be present in “higher order” processes of attention regardless of task domain (Posner & DiGirolamo, 1998; Posner & Rothbart, 1998). Developmental imaging work has also supported the role of the ACC in attention and revealed that the extent of ACC activation is consistently related to a child’s observed performance on laboratory tasks, as well as parental reports of self-regulation and emotional control abilities (Posner & Rothbart, 1998), suggesting that ACC activation is integral to attentional processes from early in development.

The prefrontal cortex also plays a functional role in the deployment of attention, and in particular, attentional involvement in the processing and regulation of cognition, emotion, and behavior. This is because the prefrontal cortex is one of the primary areas with inputs and outputs to the ACC that underlie the effortful regulation of behavior (Posner & Rothbart, 1994, 1998). The ACC uses reciprocal connections between the prefrontal cortex and structures of the limbic, autonomic, visceromotor, and endocrine systems to perform the task of governing cognitive, attentional, and emotional processes (Davidson, Putnam & Larson, 2000; Davis, Bruce, & Gunnar, 2002; Lane & McRae, 2004; Luu & Tucker, 2004). The involvement of attentional control in emotional regulation strategies is therefore facilitated by the overlap in the neural circuitry via the ACC and the areas of prefrontal cortex involved in both emotion regulation and sustained attention (Beauregard, Levesque, & Paquette, 2004; Ernst et al., 1994; Rubia et al., 2008; Smith, Taylor, Brammer, Toone, & Rubia, 2006). Thus, activation within the prefrontal cortex may also play a particularly important role in the development of attention behavior in infancy that is associated with later emotion regulation development.

Despite promising theoretical conceptualizations of the development of the executive attention network and the interconnectedness of attention and emotion processes in the brain in infancy, empirical work providing data to support these ideas is limited by available methods practical for use with infants. Attentional control exerts its influence in the brain by modulating the activity of neural systems involved in information processing such that information processing in the attended channel is facilitated, while processing in irrelevant channels is inhibited (Rueda, Posner, et al., 2005; Orekhova, Stroganova, & Posikera, 2001). Therefore, neural activity measured at the scalp level is one method that can provide a direct measure of attention processes in the brain. Electroencephalogram (EEG) methodology provides a measure of neural activation that is ideal for developmental work because it is noninvasive and able to be tolerated even by very young infants. The EEG signal is a measure of brain electrical activity that is recorded via electrodes on the scalp and results from summated postsynaptic neuronal potentials firing in synchrony (Davidson, Jackson, & Larson, 2000). This synchronization of activity leads to a dominant frequency of oscillation that is measureable at electrode sites placed at specific scalp locations (e.g., Kagan, Snidman, Kahn, & Towsley, 2007). From this, measures of EEG power and event-related potentials (ERPs) can be derived that provide information about the extent and timing of cortical activity at rest and in response to specific situations or stimuli. It is also possible to derive a measure of EEG coherence, thought to reflect the presence and strength of anatomical connections in the brain (e.g., Coan & Allen, 2004; Nunez, 1981).

EEG power is the root mean square average amplitude of the EEG signal within a frequency band of interest (Pizzagalli, 2007). EEG coherence is the frequency-dependent cross-correlation of electrical signals between two scalp electrode sites (Nunez, 1981; Thatcher, Krause, & Hrybyk, 1986) and a measure of phase synchrony between spatially distinct neural generators (Mundy, Fox, & Card, 2003). Some theorists have argued that coherence provides a measurement of neural network integrations and differentiations by providing an index of the strength and number of synaptic connections between brain regions (Nunez, 1981; Thatcher, 1994). Unlike power, coherence is not affected by arousal, eyes open versus eyes closed conditions, or by changes in state (e.g., alert vs. sleepy); in this way, measures of coherence and power are independent. Thus, whereas EEG power can provide a measure of brain function, coherence can provide a measure of neural organization and development, and both may be useful in the study of the development of attention networks in infancy.

Unlike spontaneous EEG, which is recorded continuously across time and provides measures of power and coherence, ERPs are voltage oscillations in the ongoing EEG signal that are time locked to the occurrence of a specific physical or mental event (Picton et al., 2000). These potentials can be recorded at the scalp level and extracted from the continuous EEG data through a process of filtering and then averaging across like trials, which results in a waveform containing components of interest. These components occur at a particular time (latency) and amplitude and can therefore provide information about the timing and amount or extent, as well as approximate topographical location, of neural activation in response to an external stimulus or demand (Reynolds, Guy, & Zhang, 2011). In this way, ERP measures may provide valuable insight into the development of both early, automatic attentional processes, and the more effortful control of attention characteristic of executive attention that emerges later in the first year.

Despite its potential utility to provide early evidence for neural networks associated with attention in infancy, relatively little work has examined the development of executive attention in infancy using EEG methodology. Further, existing work linking EEG and attentional functioning in development has focused primarily on EEG power and ERPs; no work that we are aware of has utilized EEG coherence in relation to attention development in an infant sample. Research examining the development of EEG power across infancy and early childhood has primarily assessed the 6- to 9-Hz frequency band, which is the dominant frequency in infancy and has been shown to be involved in both cognitive and emotional processing (Bell, 2001, 2002, 2012; Fox, Henderson, Rubin, Calkins, & Schmidt, 2001; Stroganova, Orekhova, & Posilera, 1999). The 6- to 9-Hz infant alpha band is thought to approximate the adult alpha band, which has consistently been associated with attentional modulation of cortical networks in adult work (e.g., Orekhova et al., 2001; Ray & Cole, 1985).

Developmental studies have found that relative power in the 6- to 9-Hz frequency band shows a peak at central electrode sites around 7 to 10 months of age and is most evident during periods of quietly attending to a stimulus; this peak reaches maximum amplitude at 24 months of age during similar conditions (Bell & Fox, 1992; Galkina & Boravova, 1996; Marshall, Bar-Haim, & Fox, 2002; Orekhova et al., 2001; Stroganova, Orekhova, & Posikera, 1998; Stroganova et al., 1999). Further, recent work using looking time methodology during a familiarization paradigm found that 5-month-olds who had shorter looking durations (fast habituators) had higher power in 6- to 9-Hz EEG activity at all electrodes at baseline than did infants who showed longer looking (slow habituators; Diaz & Bell, 2011). This finding may be indicative of different levels of brain maturation resulting in individual differences in attention behavior in the first year (e.g., Cuevas & Bell, 2014; Marshall et al., 2002).

Evidence for the role of neural activity in attention behaviors in infancy has been found in an additional frequency band as well. Stroganova and colleagues (Orekahova, Stroganova, & Posikera, 1999; Stroganova et al., 1998) found activity of the 4- to 6-Hz theta band to be related to attention processes in infants during tasks requiring anticipation of an expected event. Specifically, activity in this frequency band increased during anticipatory attention in 7-month-olds, and at prefrontal and frontal scalp locations this increase was positively related to the amount of time infants spent engaged in attention (Stroganova et al., 1998). Theta activity is abundant in infant EEG and is therefore sometimes considered a precursor to the adult alpha rhythm (Markand, 1990; Orekhova et al., 2001). Although an increase in theta activity is known to accompany positive emotional reactions in infants (Maulsby, 1971; Nikitina, Stroganova, & Posikera, 1987; Stroganova & Posikera, 1993), these authors interpreted the enhancement of the theta rhythm over the frontal lobes during anticipatory attention as reflective of activity of the executive attention system (Stroganova et al., 1998). This was because of the effortful nature of the attention behavior involved and because a similar positive correlation between theta power at the frontal and prefrontal locations and performance on tasks that require effortful control of attention has been found in adult work (e.g., Lang, Lang, Diekmann, & Kornhuber, 1987). In follow-up work, this group also found that better attention performance was associated with higher amplitude EEG power values in both the theta and the alpha frequency band ranges in 7- to 12-month-old infants during internally (anticipatory) and externally (visual display) controlled attention tasks, although this result was strongest for EEG measured during the externally controlled attention condition (Orekhova et al., 2001). Thus, these studies provide evidence that neural activity in multiple frequency bands in infancy is related to attention development in the first year. This neural activity may be particularly related to the development of executive attention because it occurs at scalp locations associated with executive attention in adults (Orekhova et al., 2001; Ray & Cole, 1985), and is most evident during more effortful (as opposed to automatic) attention processes in infants.

A separate line of work providing information about the neural underpinnings of attention in infancy has found negative going components of the ERP that are associated with the development of attention processes (the negative component [Nc]; e.g., Courchesne, Ganz, & Norcia, 1981; Nelson, 1994) and deliberate attentional and cognitive control (the N200 component; Gehring & Willoughby, 2002; Luu, Flaisch, & Tucker, 2000; Parasuraman, 1998; Potts, Martin, Burton, & Montague, 2006; Yeung, Holroyd, & Cohen, 2005). For example, behavioral work measuring error detection in infancy has shown that by 7 months of age infants look longer (i.e., devote more attention) to an erroneous scenario than an expected one (Wynn, 1992). Berger et al. (2006) extended this work by measuring ERP during this behavioral paradigm and showed that 7-month-old infants also displayed an ERP component that discriminated correct from incorrect trials in frontal midline locations. In addition, this ERP component was identical in morphology and observed scalp location to an ERP component (the error-related negativity) found in error detection work with adults that has been determined to come from the ACC (Dehaene, Posner, & Tucker 1994). Thus, this finding was interpreted as evidence that even in the first year of life the anatomy of the executive attention system is at least partly in place and measurable at the scalp level using EEG methodology (Posner et al., 2007).

Other work using ERP methodology to examine the neural underpinnings of attention in the first year found that the amplitude of the Nc component is related to individual differences in attention behaviors and attentional engagement. The amplitude of the Nc reflects the extent of neuronal firing and is thought to be a measure of allocation of "neural attention" in response to salient stimuli or events in developmental populations (e.g., Courchesne et al., 1981; Nelson, 1994). Moreover, source localization work using high-density electrodes suggests that the cortical sources of the Nc are likely the same frontal areas associated with attention in adults (e.g., ACC and prefrontal cortex; Reynolds, Courage, & Richards, 2010; Reynolds & Richards, 2005; Richards, Reynolds, & Courage, 2010). One study, for example, found that the amplitude of the Nc component in response to novel and familiar stimuli was distinct for infants who were short lookers (fast to habituate) versus longer lookers (slow to habituate) in a familiarization epoch. Only 6-month-olds who were short lookers showed a greater amplitude of the Nc component in response to novel stimuli compared to familiar stimuli at midline frontal electrodes likely reflecting activity of the ACC (Guy, Reynolds, & Zhang, 2013). Additional studies have shown that the amplitude of the Nc is impacted by a stimuli's salience and the infants' level of attentional engagement with a stimulus (e.g., de Haan & Nelson, 1997, 1999; Reynolds et al., 2010; Reynolds & Richards, 2005). By combining ERP measures with heart rate measures of attention, Richards (2003a, 2003b) showed that the Nc is greater in amplitude during sustained attention than during attention termination. Thus, these studies provide further evidence that activity of the neural system for executive attention is present early in development and is associated with individual differences in attention behavior.

In sum, the presence of established, predictable neural networks underlying the early development of alerting, orienting, and executive attention provides a strong biological basis for increased attention control across the first year of life. The executive attention network, and in particular the ACC and the prefrontal cortex that are part of this network, are associated with the emergence of more volitional attentional control and provide a neural mechanism for the overlap among emotion, cognition, and attention processes in development. The neural network for executive attention appears to serve as a neural regulator between different areas of the brain thought to be associated with emotion and cognition processes, making it the target of much research examining the role of attention in regulatory functioning in a variety of domains. Research assessing the activation of the executive attention network is limited in developmental and infant populations. However, there is some evidence that the executive attention network is present and overlaps and coordinates with other neural systems underlying attention from early in development. Measuring neural activity at the scalp level may help to address this gap in the literature because it appears to be one way in which researchers can assess activation of the executive attention system in infants as young as 6 and 7 months of age. Although the early development of attentional control is strongly impacted by these intrinsic biological factors, the development of attentional systems is thought to be one of the most malleable (Stevens & Neville, 2013), and is therefore susceptible to extrinsic environmental influences. Thus, it is necessary to also consider the impact of salient factors in the child's environment, such as caregiver behavior, in the early development of attentional abilities.

Extrinsic caregiver influences

Despite evidence for a strong neural basis for the emergence of attention processes, conceptual and empirical work has shown that caregiver behavior also plays a role in the development of biological and behavioral regulatory processes involved in attentional control (Calkins & Hill, 2007; Crockenberg & Leerkes, 2004; Fox & Calkins, 2003; Swingler, Perry, Calkins, & Bell, in press). Others (e.g., Calkins, 2004, 2008; Grossmann & Grossmann, 1991; Kopp, 1982; Kopp & Neufeld, 2003; Posner & Rothbart, 1998) have further suggested that the reason that early caregiving is critical to infants' developing capacities for self-regulated attention and emotion is that these processes develop in the context of an infant–caregiver dyad in which caregivers initially act as external regulators of their infant's regulatory rhythms, affect, and attention, thereby exerting direct influence over both biological and behavioral processes.

A biopsychosocial perspective motivates multilevel research to assess relations between social influences and biological and behavioral indicators of the factors that may be implicated in developmental pathways to attentional control, emotion regulation, and child adjustment. Therefore, in the following section, we consider the way in which social

https://doi.org/10.1017/S0954579415000085 Published online by Cambridge University Press

interactions between caregivers and infants play a role in the development of attention at both a biological and a behavioral level. Understanding social influences on each level of child functioning allows us to better capture the complex associations between extrinsic and intrinsic factors for developmental outcomes and may be more informative than considering levels in isolation. Given that the focus of the majority of work linking caregiving to attention has been conducted within the emotion realm, we begin with a focus on theoretical and empirical work addressing caregiver influences on the development and use of infants' attention-based behaviors to regulate emotion, and then transition to a review of current literature regarding the role of caregiver behaviors for developing neurophysiological processes underlying attention.

Caregiver influences on attention behaviors

The early life of the infant is primarily concerned with the regulation of state and distress, and attention-based behaviors are one mechanism through which independent control of arousal and regulation of affect is attained. To the extent that the caregiver can appropriately read infant signals early in development and respond in ways that minimize an infant's distress or elicit positive interaction, the infant will learn from and integrate these experiences into an emerging behavioral repertoire of regulatory skills (Calkins, Graziano, Berdan, Keane, & Degnan, 2008). Posner and Rothbart (1998) have noted that prior to 3 months of age, caregivers are heavily involved in helping the infant to regulate his or her own state and report holding and rocking as the main means of quieting the infant. However, beginning around 3 months of age, many caregivers (especially in Western cultures) report attempting to redirect infant attention by distracting their infants from distress and bringing their attention to positive or neutral stimuli (Posner & Rothbart, 1998). As infants attend to neutral stimuli, they are often quieted and distress diminishes (Harman, Rothbart, & Posner, 1997). Thus, early control of orienting and attention processes, which serves to diminish distress and negative affect for the infant, is largely in the hands of caregivers and dependent on their ability to utilize attention processes in this way (Posner & Rothbart, 1998).

During the second half of the first year, more direct control of attention passes from the caregiver to the infant, such that the infant becomes increasingly able to employ independent attentional strategies to self-regulate, or engage caregiver attention when needed. A history of shared experiences that are effective in reducing infants' arousal may lead infants to independently employ attention strategies in challenging situations that have been effective in reducing distress in the past. By establishing synchronous and well-regulated communicative patterns, caregivers can create a coregulatory context in which infants associate their own behaviors and the caregiver's behaviors with accompanying changes in their emotional state and arousal (Gianino & Tronick, 1988; Kopp, 1989). For instance, caregivers may engage in facial and vocal cues that distract infants when they are distressed, thereby introducing the redirection of infant attention as an emotion regulation strategy. By utilizing distraction techniques, caregivers give infants opportunities to learn that shifts in attention can coincide with decreases in negative affect (Spinrad & Stifter, 2002). Infants who repeatedly experience reduced negative affect through these interactions may then develop and repeat similar behaviors when confronting challenging situations independently. In this way, the same attentional mechanisms that initially get practiced through repeated dyadic interactions may provide the basis for the emergence of independent comforting and distraction behavior used to regulate emotion in early infancy, and lay the groundwork for more effortful control of emotion and cognition in late infancy and early childhood (Posner & Rothbart, 1998).

Cross-sectional and longitudinal studies have supported the association between caregiving behavior during dyadic interaction and the child's use of attention-based regulatory strategies. Calkins and Johnson (1998), for example, found that when mothers used more positive guidance, their 18-month-old infants engaged in more distraction and gaze aversion strategies during frustrating events. Conversely, negative maternal behaviors, including overcontrol and intrusiveness across a variety of contexts, have been found to be negatively related to the use of distraction and sustained attention in a sample of toddlers (Calkins, Smith, Gill, & Johnson, 1998). This relation has been demonstrated earlier in life as well; mothers and fathers who were more sensitive had 4-month-old infants who displayed increased attention orienting toward a caregiver during a challenge (Braungart-Rieker, Garwood, Powers, & Notaro, 1998). Similarly, mothers who were more sensitive in interactions that took place prior to a still-face episode had infants who showed more attention-seeking behaviors (e.g., looking to her, smiling, and reaching) and greater positive affect during the still-face episode (Kogan & Carter, 1996; Mesman, van IJzendoorn, & Bakermans-Kranenburg, 2009).

Finally, joint attention work has shown that infants who spend more time engaged in collaborative joint attention during a parent-involved frustration task avert their attention away from the object of frustration more frequently, providing support for the suggestion that parents who establish shared attention during interaction may facilitate the development of the infant's ability to use his or her own attention to reduce distress (Morales, Mundy, Crowson, Neal, & Delgado, 2005). Thus, there is clear empirical evidence that attentional processes that serve to help the infant regulate arousal and affect independently are learned in the context of repeated dyadic interactions with a caregiver early in development. However, variability in caregivers' sensitivity to cues from the infant and effectiveness at using attentional strategies to help the infant regulate early in life appear to be related to individual differences in infants' use of attention strategies to help regulate themselves during challenging situations.

Although these findings suggest a link between caregiver behavior during dyadic interaction and infants' use of

https://doi.org/10.1017/S0954579415000085 Published online by Cambridge University Press

attention control in the service of emotion regulation, almost no empirical work has examined the influence of early caregiving behavior on the child's developing attention abilities outside of an emotional or challenging context. This is despite theoretical work postulating (a) the importance of early caregiving behavior for the child's regulatory development in the first year, and (b) the importance of the child's early emerging attention abilities for subsequent emotion regulation. Thus, understanding the influence of caregiving behavior on attention processes on multiple levels of functioning may be a critical component to understanding how environmental factors influence pathways to adaptive development in infancy.

Caregiving influences on neurophysiological underpinnings of attention

Although the majority of the focus in the empirical literature has been on the ways that caregiver behavior effects behavioral manifestations of attention behaviors supporting emotion regulation, a growing body of theoretical and empirical work has suggested that caregivers may also influence children's functioning at a biological level (Calkins & Hill, 2007; Propper & Moore, 2006). Because emergent attentional development and regulation strategies are thought to be partially dependent on the basic control of physiological processes (Porges, 2003) and neurological organization (Rothbart et al., 2007), caregiver behavior that supports each of these early in development should lead to children who are more successful at controlling attention, emotion, and behavior (Calkins et al., 2008).

Most work examining the effects of caregiving behavior on children's physiological functioning has focused on autonomic measures of cardiac vagal regulation in the context of emotional challenge. In general, this work has found that mothers who are sensitive and engage in more responsive parenting and mutual affect regulation have children with better autonomic functioning at rest and in response to a challenge, while more maternal intrusiveness and restrictive parenting is associated with less optimal patterns of autonomic functioning (Calkins et al., 1998, 2008; Haley & Stansbury, 2003; Moore & Calkins, 2004). This is evidence that caregiving behaviors influence physiological functioning of the autonomic nervous system associated with regulation, but neural systems of attention in the central nervous system are also likely to be influenced by environmental input because they demonstrate such pronounced plasticity and malleability in early development (e.g., Stevens & Neville, 2013).

Emerging empirical work has begun to provide evidence that early relational experiences are closely related to neural development. This work is predicated on the notion that basic neural circuitry established during the first years of life lays the groundwork for later changes (e.g., Propper & Moore, 2006) and is capable of being molded by the social environment (De Bellis, 2001; Gunnar, Fisher, & the Early Experience, Stress, and Prevention Network, 2006; Nelson, 2000; Propper & Moore, 2006). Work on neuroplasticity has demonstrated that longer developmental trajectories are associated with more malleability in a neural system as a result of the prolonged period of time in which they are susceptible to environmental input (Stevens & Neville, 2013). Social experience is thought to be especially salient in the first 2 years of life when a spurt in brain growth characterized by an overproduction of synapses occurs (Nelson, Thomas, & de Haan, 2006). During this process, environmental experiences are thought to directly influence the synaptic connections that persist and are strengthened, or which are selectively eliminated due to lack of use (Greenough & Black, 1992; Nelson & Bloom, 1997; Singer, 1995). Thus, a caregivers' ability to facilitate regulated experiences using attention early in development may have long-term effects on the structure and function of neural systems for attention. Caregivers create environments for the infant in which adaptive, or maladaptive, neurological organization is facilitated through the activation of specific brain areas that can have the direct effect of creating and/or strengthening synaptic connections between these areas (Black & Greenough, 1986; Cicchetti & Lynch, 1995). In effect, this may be how the caregiving environment directly influences the hardwiring of the neural networks for attention in development.

Some support for this hypothesis has been found in animal research and studies of impoverished and abnormal social environments characterized by neglect or abuse (Chugani et al., 2001; Curtis & Cicchetti, 2007; Gunnar et al., 2006; Marshall & Fox, 2004; McEwen, 1999; Rutter & O'Connor, 2004). These studies have shown repeatedly that poor environmental experiences are related to abnormal structural (e.g., De Bellis, 2001) and functional (e.g., Rutter & O'Connor, 2004) brain development. Evidence from animal models shows that caregiving affects infant's biological and behavioral systems of regulation through the environment the caregiver provides, rather than through inherited traits. For example, Meaney and colleagues found that high levels of certain maternal caregiving behaviors in rodents affected the neurological systems associated with stress responses that have long-term influence on stress-related illness, physiological, and cognitive functioning in their offspring (Champagne & Meaney, 2001; Francis, Caldji, Champagne, Plotsky, & Meaney, 1999). These maternal behaviors were important in the nursing "foster" mother, rather than a biological mother, indicating early caregiving experience, rather than biology, as the critical factor affecting neural development and later functioning (Champagne & Meaney, 2001). Similarly, in a sample of human infants, Hane and Fox (2006) found that variation in quality of parenting among mother–infant dyads was related to different patterns of frontal brain activity as measured by infants' EEG asymmetry. Thus, the early social environment can have a direct effect on the experience-dependent maturation and organization of neural systems that may function to promote adaptive or maladaptive outcomes.

Caregiver influences on the neural underpinnings of attentional control have not been well examined. Nevertheless, in the same way that a history of dyadic interactions with a caregiver who effectively uses attention-based distraction techniques to regulate the infant may lead to the infant learning how to modulate his or her own behavior, repeated experience in these dyadic interactions may also be strengthening connections and patterns of responding at the *neural* level. Posner and Rothbart (2000) contend that attention has the effect of boosting activity in brain areas involved in processing information in the environment (e.g., language areas in the case of word stimuli). Thus, one way that caregiver–infant interactions may train the infant in the control of distress is by creating situations in which the infant's attention is focused (or redirected) away from a negative or distress-inducing stimulus, as a result activating neural connections in the brain that are associated with attention, engagement, and positivity, for example, rather than with negativity or stress. Activation of these brain areas then has the effect of strengthening and shaping the connections between the prefrontal and midfrontal areas that have been shown to underlie attentional control and the ability to manage emotional arousal to produce regulated behavior later in development. Contrast this with a caregiver who is not able to effectively redirect an infant from a distressing or negativity inducing situation; in this case, a different set of neural connections remains activated for an extended period while the infant continues to experience distress and likely an elevated stress response related to this experience. This process would have long-reaching consequences for the child, because challenges requiring similar effortful control of attention and behavior arise later in toddlerhood and early childhood, and the neurological system for regulating brain areas involved in these processes has been "primed" by these early experiences. Thus, depending on the child's experiences with a caregiver early in infancy, he or she may be activating a network of well-established neural connections for regulating input between brain areas necessary for dealing with these challenges, or the child may be activating a network associated with the experience of negativity and stress, which is less likely to deal effectively with these challenges and likely to instead elicit maladaptive behavior.

Although no work that we are aware of has tested these ideas specifically, there is evidence that experience with an adult can have a direct influence on brain activity associated with attention processes in development. Striano, Reid, and Hoehl (2006) examined the effect of engagement in joint attention with an adult on the attentional Nc component of the ERP in 9-month-old infants. Their results indicated that the Nc displayed a larger peak amplitude (indicating greater allocation of "neural attention") in response to viewing an object when infants viewed the object following interactive joint attention with an adult relative to a non-joint-attention interaction. Although not directly testing the ideas we are suggesting here, this result provides some early support for the idea that interaction with an adult can have an effect on activation of attention systems at the neural level. In addition, the direction of this effect suggests that joint attentional engagement between an infant and an adult, like that which occurs in sensitive and responsive caregiving, results in an *increase* in activity of areas of the brain that have been shown to underlie executive attention in development. This is promising evidence that one role of sensitive caregiving behavior early in development may be to increase activity in brain areas associated with neural networks of attention, thereby strengthening connections between these areas and helping to create a neural network for attentional control.

Translational Implications

Longitudinal work examining developmental processes across multiple developmental domains and at multiple levels of child functioning can provide much-needed information about the etiology of developmental psychopathology, thereby providing targets and early points of entry for translational and intervention work designed to alter trajectories of maladjustment. The development of attentional control is an important focus of work like this, because it has been shown to be foundational to functioning in a variety of domains and linked with multiple pathological disorders, including attention-deficit/hyperactivity disorder, anxiety, and depression (Casey et al., 1997; Swanson et al., 1991). Throughout this paper, we underscore that the development of attention and underlying neural networks show a high degree of plasticity, making attentional control a good candidate for successful intervention. Recent intervention work designed to target other aspects of functioning has been shown to be effective in changing the neural mechanisms of selective attention in typically developing preschool and early school-aged children, as well as in children with learning problems and children who are at risk for reading impairments (Stevens, Coch, Sanders, & Neville, 2008; Stevens et al., 2013; Yamada, Stevens, Harn, Chard, & Neville, 2011). In all cases, increases in effects of attention on neural processing were associated with behavioral changes in other domains, highlighting the importance of attention in overall development and suggesting that interventions targeting attention and underlying neural networks could have far-reaching implications for behavior and adaptive functioning.

Perhaps as a result of the broad influence of attention on adjustment in a variety of developmental domains, attention training has recently been implicated in curricula for preschool and school-age children. Thus, researchers have been able to demonstrate that attentional training is associated with improvements in behavioral and neurophysiological indices of attention, as well as with measures of academic outcomes and nonverbal intelligence (Bodrova & Leong, 2007; Chenault, Thomson, Abbott, & Berninger, 2006; Diamond, Barnett, Thomas, & Munro, 2007; Rueda, Rothbart, et al., 2005). Most central to our focus here is evidence from a family-based training program designed to improve brain systems for selective attention in preschool children (Neville et al., 2013). In an evaluation study of this program low socioeconomic status preschoolers were randomly assigned to the training group, which combined training sessions for caregivers as well as attention training for children, or one of two control groups (Neville et al., 2013). Results indicated that electrophysiological measures of children's brain functions (ERPs) supporting selective attention, standardized measures of cognition, and parent-reported child behaviors all favored children in the treatment group relative to both control groups. In addition, the most favorable outcomes were observed in more parent-focused (as opposed to child-focused) training models. This study further highlights the plasticity of neural networks underlying attention and provides evidence that interventions targeting child attention, as well as caregiver behaviors that support children's attentional capabilities, can influence neural mechanisms of attentional control. Results of this work also support the idea that caregiving behavior has a direct effect on the development of neural systems underlying attention. Thus, caregiver behavior that supports the early development of attentional control in infancy may be an important target of applied work and future interventions designed to support and promote adaptive child functioning across a variety of emotional, social, cognitive, and academic domains.

Conclusions

Understanding the early development of attention is critical for understanding pathways to adaptive child functioning in a variety of domains, including emotion regulation and early developing problem behaviors (Bell & Calkins, 2012; Calkins, 2008; Calkins et al., 2008). We have focused on the development of attention during early infancy and illustrated that shifts in attention skills across the first 12 months of life are fundamental to shifts in emotion regulation that are also observed during this period. Given these early links, we along with others (e.g., Bell & Calkins, 2012; Fox & Calkins, 2003; Posner & Rothbart, 1998; Rothbart et al., 1994, 2007) suggest that early attentional processes may be one mechanism through which infants gain control of emotional arousal, regulate affective expression, and begin to develop more sophisticated attention-based behavioral strategies during early childhood.

As we show in the current paper, both intrinsic biological factors and extrinsic environmental factors, measured at multiple levels of child functioning and in the context of one another, are influential to the emergence of attentional control (Cicchetti, 1984, 1993; Cicchetti & Rogosch, 1996; Sroufe & Rutter, 1984). The executive attention network, specifically, seems to be a primary intrinsic neural mechanism through which attention and emotion become integrated in the first year. However, a caregiver's effectiveness at using control of attention to help infants regulate also has a direct influence on attention behaviors and may have long-term effects on the biological structure and function of the developing executive attention network (Black & Greenough, 1986; Cichetti & Lynch, 1995).

We have suggested that if caregiving behaviors in the first year of life influence the neuroanatomical development of the executive attention network, we should see an effect of caregiving behavior in the first year on attention-based behavior and associated neural activity. In addition, because the early development of attention abilities have been theorized to provide the foundation for later emotion regulation development, from a timing perspective, it may be that early caregiving behaviors have the most influence on the development of attention behavior and associated neural underpinnings, which then influence later emotion regulation behaviors as a result of dependence on many of the same neural areas. Thus, caregiver influence on neural activation associated with the organization of the executive attention network in development may be a mechanism through which maternal caregiving behavior influences the development of infants' attentional control and subsequent abilities such as emotion regulation and effortful control. No work that we are aware of has empirically tested these ideas with infants, but examining these questions in longitudinal, process-oriented models of regulatory development that incorporate multiple levels of analysis, including the neural, behavioral, and environmental, will be integral to understanding both normative and nonnormative development of attention control, which may have downstream effects for functioning in areas that rely on the attention control such as emotion regulation.

References

Bakermans-Kranenburg, M. J., van IJzendoorn, M. H., Pijlman, F. T., Mesman, J., & Juffer, F. (2008). Experimental evidence for differential susceptibility: Dopamine D4 receptor polymorphism (DRD4 VNTR) moderates intervention effects on toddlers' externalizing behavior in a randomized controlled trial. *Developmental Psychology*, *44*, 293–300.

Beauregard, M., Levesque, J., & Paquette, V. (2004). Neural basis of conscious and voluntary self-regulation of emotion. In M. Beauregard (Ed.), *Consciousness, emotional self-regulation and the brain* (pp. 163–194). Philadelphia, PA: John Benjamins.

Beck, A. T. (1976). *Cognitive therapy and the emotional disorders*. Madison, CT: Meridian.

Bell, M. A. (2001). Brain electrical activity associated with cognitive processing during a looking version of the A-not-B object permanence task. *Infancy*, *2*, 311–330.

Bell, M. A. (2002). Power changes in infant EEG frequency bands during a spatial working memory task. *Psychophysiology*, *39*, 450–458.

Bell, M. A. (2012). A psychobiological perspective on working memory performance at 8 months of age. *Child Development*, *83*, 251–265.

Bell, M. A., & Calkins, S. D. (2012). Attentional control and emotion regulation in early development. In M. I. Posner (Ed.), *Cognitive neuroscience of attention* (2nd ed., pp. 322–330). New York: Guilford Press.

Bell, M. A., & Fox, N. A. (1992). The relations between frontal brain electrical activity and cognitive development during infancy. *Child Development*, *63*, 1142–1163.

Bell, T., Batterink, L., Currin, L., Pakulak, E., Stevens, C., & Neville, H. (2008). *Genetic influences on selective auditory attention as indexed by ERPs*. Paper presented at the Cognitive Neuroscience Society, San Francisco, CA.

https://doi.org/10.1017/S0954579415000085 Published online by Cambridge University Press

Berger, A., Tzur, G., & Posner, M. I. (2006). Infant brains detect arithmetic errors. *Proceedings of the National Academy of Sciences*, *103*, 12649–12653.

Black, J. E., & Greenough, W. T. (1986). Induction of pattern in neural structure by experience: Implications for cognitive development. *Advances in Developmental Psychology*, *4*, 1–50.

Blair, C. (2002). School readiness: Integrating cognition and emotion in a neurobiological conceptualization of children's functioning at school entry. *American Psychologist*, *57*, 111–127.

Bodrova, E., & Leong, D. (2007). *Tools of the mind: The Vygotskian approach to early childhood education* (2nd ed.). Upper Saddle River, NJ: Pearson Education.

Botwinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*, 624–652.

Braungart-Rieker, J., Garwood, M., Powers, B. P., & Notaro, P. C. (1998). Infant affect and affect regulation during the still-face paradigm with mothers and fathers: The role of infant characteristics and parental sensitivity. *Developmental Psychology*, *34*, 1428–1437.

Bronson, M. B. (2000). *Self-regulation in early childhood: Nature and nurture*. New York: Guilford Press.

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in anterior cingulate cortex. *Trends in Cognitive Sciences*, *4*, 215–222.

Calkins, S. D. (1994). Individual differences in the biological aspects of temperament. In J. E. Bates & T. D. Wachs (Eds.), *Temperament: Individual differences at the interface of biology and behavior* (pp. 199–217). Washington, DC: American Psychological Association.

Calkins, S. D. (2004). Early attachment process and the development of emotional self-regulation. In R. F. Baumeister & K. D. Vohs (Eds.), *The handbook of self-regulation*. Hillsdale, NJ: Erlbaum.

Calkins, S. D. (2008). The emergence of self-regulation: Biological and behavioral control mechanisms supporting toddler competencies. In C. Brownell & C. Kopp (Eds.), *Transitions in early socioemotional development: The toddler years*. New York: Guilford Press.

Calkins, S. D. (2010). Psychobiological models of adolescent risk: Implications for intervention and prevention. *Developmental Psychobiology*, *52*, 213–215.

Calkins, S. D. (2011). Biopsychosocial models and the study of family processes and child adjustment. *Journal of Marriage and Family*, *73*, 817–821.

Calkins, S. D., & Fox, N. A. (2002). Self-regulatory processes in early personality development: A multilevel approach to the study of childhood social withdrawal and aggression. *Development and Psychopathology*, *14*, 477–498.

Calkins, S. D., Graziano, P. A., Berdan, L. E., Keane, S. P., & Degnan, K. A. (2008). Predicting cardiac vagal regulation in early childhood from maternal–child relationship quality during toddlerhood. *Developmental Psychobiology*, *50*, 751–766.

Calkins, S. D., & Hill, A. (2007). Caregiver influences on emerging emotion regulation: Biological and environmental transactions in early development. In J. J. Gross (Ed.), *Handbook of emotion regulation* (pp. 229–248). New York: Guilford Press.

Calkins, S. D., & Johnson, M. C. (1998). Toddler regulation of distress to frustrating events: Temperamental and maternal correlates. *Infant Behavior & Development*, *21*, 379–395.

Calkins, S. D., & Keane, S. P. (2004). Cardiac vagal regulation across the preschool period: Stability, continuity, and implications for childhood adjustment. *Developmental Psychobiology*, *45*, 101–112.

Calkins, S. D., Smith, C. L., Gill, K. L., & Johnson, M. C. (1998). Maternal interactive style across contexts: Relations to emotional, behavioral, and physiological regulation during toddlerhood. *Social Development*, *7*, 350–369.

Casey, B. J., Castellanos, F., Giedd, J. N., & Marsh, W. L. (1997). Implication of right frontostriatal circuitry in response inhibition and attention-deficit/hyperactivity disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*, *36*, 374–383.

Champagne, F., & Meaney, M. J. (2001). Like mother, like daughter: Evidence for non-genomic transmission of parental behavior and stress responsivity. *Progress in Brain Research*, *133*, 287–302.

Chenault, B., Thomson, J., Abbott, R. D., & Berninger, V. W. (2006). Effects of prior attention training on child dyslexics' response to composition instruction. *Developmental Neuropsychology*, *29*, 243–260.

Chugani, H. T., Behan, M. E., Muzik, O., Juhász, C., Nagy, F., & Chugani, D. C. (2001). Local brain functional activity following early deprivation: A study of postinstitutionalized Romanian orphans. *NeuroImage*, *14*, 1290–1301.

Cicchetti, D. (1984). The emergence of developmental psychopathology. *Child Development*, *55*, 1–7.

Cicchetti, D. (1993). Developmental psychopathology: Reactions, reflections, projections. *Developmental Review*, *13*, 471–502.

Cicchetti, D., & Dawson, G. (2002). Editorial: Multiple levels of analysis. *Development and Psychopathology*, *14*, 417–420.

Cicchetti, D., & Lynch, M. (1995). Failures in the expectable environment and their impact on individual development: The case of child maltreatment. In D. Cicchetti & D. J. Cohen (Eds.), *Developmental psychopathology: Vol. 2. Risk, disorder, and adaptation* (pp. 32–71). Oxford: Wiley.

Cicchetti, D., & Posner, M. I. (2005). Editorial: Cognitive and affective neuroscience and developmental psychopathology. *Development and Psychopathology*, *17*, 569–575.

Cicchetti, D., & Rogosh, F. (1996). Equifinality and multifinality in developmental psychopathology. *Development and Psychopathology*, *4*, 597–600.

Coan, J. A., & Allen, J. B. (2004). Frontal EEG asymmetry as a moderator and mediator of emotion. *Biological Psychology*, *67*, 7–49.

Colombo, J. (2001). The development of visual attention in infancy. *Annual Review of Psychology*, *52*, 337–367.

Colombo, J. (2002). Infant attention grows up: The emergence of a developmental cognitive neuroscience perspective. *Current Directions in Psychological Science*, *11*, 196–200.

Colombo, J., & Cheatham, C. L. (2006). The emergence and basis of endogenous attention in infancy and early childhood. In R. V. Kail (Ed.), *Advances in child development and behavior* (Vol. 34, pp. 283–322). San Diego, CA: Elsevier Academic Press.

Colombo, J., Harlan, J. E., & Mitchell, D. W. (1999). *The development of look duration in infancy: Evidence for a triphasic course*. Poster presented at the annual meeting of the Society for Research in Child Development, Albuquerque, NM.

Colombo, J., Kapa, L., & Curtindale, L. (2010). Varieties of attention in infancy. In L. M. Oakes, C. H. Cashon, M. Casasola, & D. H. Rakison (Eds.), *Infant perception and cognition: Recent advances, emerging theories, and future directions* (pp. 3–26). New York: Oxford University Press.

Colombo, J., & Mitchell, D. (1990). Individual differences in early visual attention: Fixation time and information processing. In J. Colombo & J. W. Fagen (Eds.), *Individual differences in infancy: Reliability, stability, prediction* (pp. 193–227). Hillsdale, NJ: Erlbaum.

Colombo, J., Mitchell, D., Coldren, J. T., & Freeseman, L. J. (1991). Individual differences in infant visual attention: Are short lookers faster processors or feature processors? *Child Development*, *62*, 1247–1257.

Colombo, J., Mitchell, D., O'Brien, M., & Horowitz, F. D. (1987). The stability of visual habituation during the first year of life. *Child Development*, *58*, 474–487.

Courage, M. L., Reynolds, G. D., & Richards, J. E. (2006). Infants' attention to patterned stimuli: Developmental change from 3 to 12 months of age. *Child Development*, *77*, 680–695.

Courchesne, E., Ganz, L., & Norcia, A. M. (1981). Event-related brain potentials to human faces in infants. *Child Development*, *52*, 804–811.

Crockenberg, S. C., & Leerkes, E. M. (2004). Infant and maternal behaviors regulate infant reactivity to novelty at 6 months. *Developmental Psychology*, *40*, 1123–1132.

Cuevas, K., & Bell, M. (2014). Infant attention and early childhood executive function. *Child Development*, *85*, 397–404.

Curtis, W., & Cicchetti, D. (2007). Emotion and resilience: A multilevel investigation of hemispheric electroencephalogram asymmetry and emotion regulation in maltreated and nonmaltreated children. *Development and Psychopathology*, *19*, 811–840.

Davidson, R. J., Jackson, D. C., & Larson, C. L. (2000). Human electroencephalography. In J. T. Cacioppo, L. G. Tassinary, & G. G. Berntson (Eds.), *Handbook of psychophysiology* (2nd ed., pp. 27–52). New York: Cambridge University Press.

Davidson, R. J., Putnam, K. M., & Larson, C. L. (2000). Dysfunction in the neural circuitry of emotion regulation—A possible prelude to violence. *Science*, *289*, 591–594.

Davis, E. P., Bruce, J., & Gunnar, M. R. (2002). The anterior attention network: Associations with temperament and neuroendocrine activity in 6-year-old children. *Developmental Psychobiology*, *40*, 43–65.

De Bellis, M. D. (2001). Developmental traumatology: The psychobiological development of maltreated children and its implications for research, treatment, and policy. *Development and Psychopathology*, *13*, 539–564.

de Haan, M., & Nelson, C. A. (1997). Recognition of the mother's face by six-month-old infants: A neurobehavioral study. *Child Development*, *68*, 187–210.

de Haan, M., & Nelson, C. A. (1999). Brain activity differentiates face and object processing in 6-month-old infants. *Developmental Psychology*, *35*, 1113–1121.

Dehaene, S., Posner, M. I., & Tucker, D. M. (1994). Localization of a neural system for error detection and compensation. *Psychological Science*, *5*, 303–305.

Derryberry, D., & Rothbart, M. K. (1988). Arousal, affect, and attention as components of temperament. *Journal of Personality and Social Psychology*, *55*, 958–966.

Diamond, A., Barnett, W., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science*, *318*, 1387–1388.

Diaz, A., & Bell, M. A. (2011). Information processing efficiency and regulation at five months. *Infant Behavior & Development*, *34*, 239–247.

Ernst, M., Liebenauer, L. L., King, A. C., Fitzgerald, G. A., Cohen, R. M., & Zametkin, A. J. (1994). Reduced brain metabolism in hyperactive girls. *Journal of the American Academy of Child & Adolescent Psychiatry*, *33*, 858–868.

Fox, N. A. (1994). Dynamic cerebral processes underlying emotion regulation. *Monographs of the Society for Research in Child Development*, *59*, 152–166.

Fox, N. A., & Calkins, S. D. (2003). The development of self-control of emotion: Intrinsic and extrinsic influences. *Motivation and Emotion*, *27*, 7–26.

Fox, N. A., Henderson, H. A., & Marshall, P. J. (2001). The biology of temperament: An integrative approach. In C. A. Nelson, & M. Luciana (Eds.), *The handbook of developmental cognitive neuroscience* (pp. 631–645). Cambridge, MA: Springer.

Fox, N. A., Henderson, H. A., Rubin, K. H., Calkins, S. D., & Schmidt, L. A. (2001). Continuity and discontinuity of behavioral inhibition and exuberance: Psychophysiological and behavioral influences across the first four years of life. *Child Development*, *72*, 1–21.

Fox, E., Russo, R., & Dutton, K. (2002). Attentional bias for threat: Evidence for delayed disengagement from emotional faces. *Cognition and Emotion*, *16*, 355–379.

Francis, D. D., Caldji, C., Champagne, F., Plotsky, P. M., & Meaney, M. J. (1999). The role of corticotropin-releasing factor–norepinephrine systems in mediating the effects of early experience on the development of behavioral and endocrine responses to stress. *Biological Psychiatry*, *46*, 1153–1166.

Frick, J. E., Colombo, J., & Saxon, T. F. (1999). Individual and developmental differences in disengagement of fixation in early infancy. *Child Development*, *70*, 537–548.

Gao, W., Zhu, H., Giovanello, K. S., Smith, J. K., Shen, D., Gilmore, J. H., et al. (2009). Evidence on the emergence of the brain's default network from 2-week-old to 2-year-old healthy pediatric subjects. *Proceedings of the National Academy of Sciences*, *106*, 6790–6795.

Galkina, N. S., & Boravova, A. I. (1996). The formation of EEG mu- and alpha-rhythms in children during the second–third years of life. *Human Physiology*, *22*, 540–545.

Gehring, W. J., & Willoughby, A. R. (2002). Are all medial frontal negativities created equal? Toward a richer empirical basis for theories of action monitoring. In M. Ullsperger & M. Falkenstein (Eds.), *Errors, conflicts, and the brain: Current opinions on performance monitoring* (pp. 14–20). Leipzig: Max Planck Institute of Cognitive Neuroscience.

Gianino, A. A., & Tronick, E. Z. (1988). The mutual regulation model: The infant's self and interactive regulation and coping and defensive capacities. In T. M. Field, P. M. McCabe, & N. Schneiderman (Eds.), *Stress and coping across development* (pp. 47–68). Hillsdale, NJ: Erlbaum.

Goldapple, K., Segal, Z., Garson, C., Lau, M., Bieling, P., Kennedy, S., et al. (2004). Modulation of cortical–limbic pathways in major depression. *Archives of General Psychiatry*, *61*, 34–41.

Gottlieb, G. (1997). A systems view of psychobiological development. In D. Magnusson (Ed.), *The lifespan development of individuals: Behavioral, neurobiological, and psychosocial perspectives: A synthesis* (pp. 76–103). New York: Cambridge University Press.

Greenough, W. T., & Black, J. E. (1992). Induction of brain structure by experience: Substrates for cognitive development. In M. R. Gunnar & C. A. Nelson (Eds.), *Developmental behavioral neuroscience* (pp. 155–200). Hillsdale, NJ: Erlbaum.

Grolnick, W. S., Bridges, L. J., & Connell, J. P. (1996). Emotion regulation in two-year-olds: Strategies and emotional expression in four contexts. *Child Development*, *67*, 928–941.

Grossmann, K. E., & Grossmann, K. (1991). Attachment quality as an organizer of emotional and behavioral responses in a longitudinal perspective. In C. Parkes, J. Stevenson-Hinde, & P. Marris (Eds.), *Attachment across the life cycle* (pp. 93–114). New York: Tavistock/Routledge.

Gunnar, M. R., & Fisher, P. A., & the Early Experience, Stress, and Prevention Network (2006). Bringing basic research on early experience and stress neurobiology to bear on preventive interventions for neglected and maltreated children. *Development and Psychopathology*, *18*, 651–677.

Guy, M. W., Reynolds, G. D., & Zhang, D. (2013). Visual attention to global and local stimulus properties in 6-month-old infants: Individual differences and event-related potentials. *Child Development*, *84*, 1392–1406.

Haley, D. W., & Stansbury, K. (2003). Infant stress and parent responsiveness: Regulation of physiology and behavior during still-face and reunion. *Child Development*, *74*, 1534–1546.

Hane, A., & Fox, N. A. (2006). Ordinary variations in maternal caregiving influence human infants' stress reactivity. *Psychological Science*, *17*, 550–556.

Harman, C., Rothbart, M. K., & Posner, M. I. (1997). Distress and attention interactions in early infancy. *Motivation and Emotion*, *21*, 27–43.

Jankowski, J. J., & Rose, S. A. (1997). The distribution of visual attention in infants. *Journal of Experimental Child Psychology*, *65*, 127–140.

Johnson, M. H., Posner, M. I., & Rothbart, M. K. (1991). Components of visual orienting in early infancy: Contingency learning, anticipatory looking, and disengaging. *Journal of Cognitive Neuroscience*, *3*, 335–344.

Kagan, J., Snidman, N., Kahn, V., & Towsley, S. (2007). The preservation of two infant temperaments into adolescence. *Monographs of the Society for Research in Child Development*, *72*, 1–95.

Keenan, K. (2000). Emotion dysregulation as a risk factor for child psychopathology. *Clinical Psychology: Science and Practice*, *7*, 418–434.

Kindt, M., & Van Den Hout, M. (2001). Selective attention and anxiety: A perspective on developmental issues and the causal status. *Journal of Psychopathology and Behavioral Assessment*, *23*, 193–202.

Kogan, N., & Carter, A. S. (1996). Mother–infant reengagement following the still-face: The role of maternal emotional unavailability and infant affect regulation. *Infant Behavior & Development*, *19*, 359–370.

Kopp, C. B. (1982). Antecedents of self-regulation: A developmental perspective. *Developmental Psychology*, *18*, 199–214.

Kopp, C. B. (1989). Regulation of distress and negative emotions: A developmental view. *Developmental Psychology*, *25*, 343–354.

Kopp, C. B. (2002). Commentary: The Codevelopments of attention and emotion regulation. *Infancy*, *3*, 199–208.

Kopp, C. B., & Neufeld, S. J. (2003). Emotional development during infancy. In R. J. Davidson, K. R. Scherer, & H. Goldsmith (Eds.), *Handbook of affective sciences* (pp. 347–374). New York: Oxford University Press.

Lane, R. D., & McRae, K. (2004). Neural substrates of conscious emotional experience: A cognitive–neuroscientific perspective. In M. Beauregard (Ed.), *Consciousness, emotional self-regulation and the brain* (pp. 87–122). Amsterdam: John Benjamins.

Lang, M., Lang, W., Diekmann, V., & Kornhuber, H.H. (1987). The frontal theta rhythm indicating motor and cognitive learning. *Electroencephalography and Clinical Neurophysiology 40*(Suppl.), 322–327.

Lansink, J. M., & Richards, J. E. (1997). Heart rate and behavioral measures of attention in six-, nine-, and twelve-month-old infants during object exploration. *Child Development*, *68*, 610–620.

Luthar, S. S., Cicchetti, D., & Becker, B. (2000). The construct of resilience: A critical evaluation and guidelines for future work. *Child Development*, *71*, 543–562.

Luu, P., Flaisch, T., & Tucker, D. M. (2000). Medial frontal cortex in action monitoring. *Journal of Neuroscience*, *20*, 464–469.

Luu, P., & Tucker, D. M. (2004). Self-regulation by the medial frontal cortex: Limbic representation of motive set-points. In M. Beauregard (Ed.), *Consciousness, emotional self-regulation and the brain* (pp. 123–161). Amsterdam: John Benjamins.

Markand, O. N. (1990). Alpha rhythms. *Journal of Clinical Neurophysiology*, *7*, 163–190.

Marshall, P. J., Bar-Haim, Y., & Fox, N. A. (2002). Development of the EEG from 5 months to 4 years of age. *Clinical Neurophysiology*, *113*, 1199–1208.

Marshall, P. J., & Fox, N. A. (2004). A comparison of the electroencephalogram between institutionalized and community children in Romania. *Journal of Cognitive Neuroscience*, *16*, 1327–1338.

Maulsby, R. L. (1971). An illustration of emotionally evoked theta rhythm in infancy: Hedonic hypersynchrony. *Electroencephalography & Clinical Neurophysiology*, *31*, 157–165.

Mayberg, H. S. (2003). Modulating dysfunctional limbic–cortical circuits in depression: Towards development of brain-based algorithms for diagnosis and optimised treatment. *British Medical Bulletin*, *65*, 193–207.

McEwen, B. (1999). Development of the cerebral cortex: XIII. Stress and brain development: II. *Journal of the American Academy of Child & Adolescent Psychiatry*, *38*, 101–103.

Mesman, J., van IJzendoorn, M. H., & Bakermans-Kranenburg, M. J. (2009). The many faces of the still-face paradigm: A review and meta-analysis. *Developmental Review*, *29*, 120–162.

Moore, G. A., & Calkins, S. D. (2004). Infants' vagal withdrawal in the still-face paradigm is related to dyadic coordination of mother–infant interaction. *Developmental Psychology*, *40*, 1068–1080.

Morales, M., Mundy, P., Crowson, M. M., Neal, A., & Delgado, C. F. (2005). Individual differences in infant attention skills, joint attention, and emotion regulation behaviour. *International Journal of Behavioral Development*, *29*, 259–263.

Mundy, P., Fox, N., & Card, J. (2003). EEG coherence, joint attention and language development in the second year. *Developmental Science*, *6*, 48–54.

Nelson, C. A. (1994). Neural correlates of recognition memory in the first postnatal year. In G. Dawson & K. W. Fischer (Eds.), *Human behavior and the developing brain* (pp. 269–313). New York: Guilford Press.

Nelson, C. A. (2000). The neurobiological bases of early intervention. In J. P. Shonkoff & S. J. Meisels (Eds.), *Handbook of early childhood intervention* (2nd ed., pp. 204–227). New York: Cambridge University Press.

Nelson, C. A., & Bloom, F. E. (1997). Child development and neuroscience. *Child Development*, *68*, 970–987.

Nelson, C. A., Thomas, K. M., & de Haan, M. (2006). Neural bases of cognitive development. In D. Kuhn, R. S. Siegler, W. Damon, & R. M. Lerner (Eds.), *Handbook of child psychology: Vol. 2. Cognition, perception, and language* (6th ed., pp. 3–57). Hoboken, NJ: Wiley.

Neville, H., Stevens, C., Pakulak, E., Bell, T., Fanning, J., Klein, S., et al. (2013). Family based training program improves brain function, cognition, and behavior in lower socioeconomic status preschoolers. *Proceedings of the National Academy of Science*. Advance online publication.

Nikitina, G. M., Stroganova, T. A., & Posikera, I. N. (1987). Central organization of emotional reactions of infants during the first year of life. In S. Trojan & F. Stastny (Eds.), *Ontogenesis of the brain* (pp. 223–228). Prague: Universitas Carolina.

Nunez, P. L. (1981). *Electric fields of the brain: The neurophysics of EEG*. New York: Oxford University Press.

Orekhova, E. V., Stroganova, T. A., & Posikera, I. N. (1999). Theta synchronization during sustained anticipatory attention in infants over the second half of the first year of life. *International Journal of Psychophysiology*, *32*, 151–172.

Orekhova, E. V., Stroganova, T. A., & Posikera, I. N. (2001). Alpha activity as an index of cortical inhibition during sustained internally controlled attention in infants. *Clinical Neurophysiology*, *112*, 740–749.

Parasuraman, R. (1998). *The attentive brain*. Cambridge, MA: MIT Press.

Picton, T. W., Bentin, S. S., Berg, P. P., Donchin, E. E., Hillyard, S. A., Johnson, R., et al. (2000). Guidelines for using human event-related potentials to study cognition: Recording standards and publication criteria. *Psychophysiology*, *37*, 127–152.

Pizzagalli, D. A. (2007). Electroencephalography and high-density electrophysiological source localization. In J. Cacioppo, L. G. Tassinary, & G. G. Bernston (Eds.), *Handbook of psychophysiology* (Vol. 2, pp. 56–84). New York: Cambridge University Press.

Porges, S. W. (2003). The polyvagal theory: Phylogenetic contributions to social behavior. *Physiology & Behavior*, *79*, 503–513.

Posner, M. I., & Dehaene, S. (1994). Attentional networks. *Trends in Neurosciences*, *17*, 75–79.

Posner, M. I., & DiGirolamo, G. J. (1998). Executive attention: Conflict, target detection, and cognitive control. In R. Parasuraman (Ed.), *The attentive brain* (pp. 401–423). Cambridge, MA: MIT Press.

Posner, M. I., & Fan, J. (2008). Attention as an organ system. In J. R. Pomerantz (Ed.), *Topics in integrative neuroscience* (pp. 31–61). New York: Cambridge University Press.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience*, *13*, 25–42.

Posner, M. I., & Rothbart, M. K. (1994). Attentional regulation: From mechanism to culture. In P. Bertelson, P. Eelen, & G. Ydewalle (Eds.), *International perspectives on psychological science: Leading themes* (pp. 41–55). East Sussex: Psychology Press.

Posner, M. I., & Rothbart, M. K. (1998). Summary and commentary: Developing attentional skills. In J. E. Richards (Ed.), *Cognitive neuroscience of attention: A developmental perspective* (pp. 317–323). Mahwah, NJ: Erlbaum.

Posner, M. I., & Rothbart, M. K. (2000). Developing mechanisms of self-regulation. *Development and Psychopathology*, *12*, 427–441.

Posner, M. I., & Rothbart, M. K. (2009). Toward a physical basis of attention and self-regulation. *Physics of Life Reviews*, *6*, 103–120.

Posner, M. I., Rothbart, M. K., Sheese, B. E., & Tang, Y. (2007). The anterior cingulate gyrus and the mechanism of self-regulation. *Cognitive, Affective, & Behavioral Neuroscience*, *7*, 391–395.

Posner, M. I., Rothbart, M. K., Sheese, B. E., & Voelker, P. (2012). Control networks and neuromodulators of early development. *Developmental Psychology*, *48*, 827–835.

Potts, G. F., Martin, L. E., Burton, P., & Montague, P. (2006). When things are better or worse than expected: The medial frontal cortex and the allocation of processing resources. *Journal of Cognitive Neuroscience*, *18*, 1112–1119.

Propper, C., & Moore, G. A. (2006). The influence of parenting on infant emotionality: A multilevel psychobiological perspective. *Developmental Review*, *26*, 427–460.

Ray, W. J., & Cole, H. W. (1985). EEG alpha activity reflects attentional demands, and beta activity reflects emotional and cognitive processes. *Science*, *228*, 750–752.

Reynolds, G. D., Courage, M. L., & Richards, J. E. (2010). Infant attention and visual preferences: Converging evidence from behavior, event-related potentials, and cortical source localization. *Developmental Psychology*, *46*, 886–904.

Reynolds, G. D., Guy, M. W., & Zhang, D. (2011). Neural correlates of individual differences in infant visual attention and recognition memory. *Infancy*, *16*, 368–391.

Reynolds, G. D., & Richards, J. E. (2005). Familiarization, attention, and recognition memory in infancy: An event-related potential and cortical source localization study. *Developmental Psychology*, *41*, 598–615.

Richards, J. E. (2003a). Attention affects the recognition of briefly presented visual stimuli in infants: An ERP study. *Developmental Science*, *6*, 312–328.

Richards, J. E. (2003b). Cortical sources of event-related potentials in the prosaccade and antisaccade task. *Psychophysiology*, *40*, 878–894.

Richards, J. E., & Casey, B. J. (1990). Infant visual recognition memory performance as a function of heart rate defined phases of attention. *Infant Behavior & Development*, *13*, 585.

Richards, J. E., Reynolds, G. D., & Courage, M. L. (2010). The neural bases of infant attention. *Current Directions in Psychological Science*, *19*, 41–46.

Rothbart, M. K. (1981). Measurement of temperament in infancy. *Child Development*, *52*, 569–578.

Rothbart, M. K. (1986). Longitudinal observation of infant temperament. *Developmental Psychology*, *22*, 356.

Rothbart, M. K., & Bates, J. E. (1998). Temperament. In N. Eisenberg (Ed.), *Handbook of child psychology: Vol. 3. Social, emotional, and personality development* (5th ed., pp. 105–176). New York: Wiley.

Rothbart, M. K., & Posner, M. I. (2006). Temperament, attention, and developmental psychopathology. In D. Cicchetti & D. J. Cohen (Eds.), *Developmental psychopathology: Vol 2. Developmental neuroscience* (2nd ed., pp. 465–501). Hoboken, NJ: Wiley.

Rothbart, M. K., Posner, M. I., & Boylan, A. (1990). Regulatory mechanisms in infant development. In J. T. Enns (Ed.), *The development of attention: Research and theory* (pp. 47–66). Oxford: North–Holland.

Rothbart, M. K., Posner, M. I., & Rosicky, J. (1994). Orienting in normal and pathological development. *Development and Psychopathology*, *6*, 635–652.

Rothbart, M. K., Sheese, B. E., & Posner, M. I. (2007). Executive attention and effortful control: Linking temperament, brain networks, and genes. *Child Development Perspectives*, *1*, 2–7.

Rubia, K., Halari, R., Smith, A., Mohammed, M., Scott, S., Giampietro, V., et al. (2008). Dissociated functional brain abnormalities of inhibition in boys with pure conduct disorder and in boys with pure attention deficit hyperactivity disorder. *American Journal of Psychiatry*, *165*, 889–897.

Rueda, M., Posner, M. I., & Rothbart, M. K. (2005). The development of executive attention: Contributions to the emergence of self-regulation. *Developmental Neuropsychology*, *28*, 573–594.

Rueda, M. R., Rothbart, M. K., McCandliss, B. D., Saccomanno, L., & Posner, M. I. (2005). Training, maturation, and genetic influences on the development of executive attention. *Proceedings of the National Academy of Sciences*, *102*, 14931–14936.

Ruff, H., & Rothbart, M. (1996). *Attention in early development: Themes and variations*. New York: Oxford University Press.

Rutter, M., & O'Connor, T. G. (2004). Are there biological programming effects for psychological development? Findings from a study of Romanian adoptees. *Developmental Psychology*, *40*, 81–94.

Sameroff, A. (2010). A unified theory of development: A dialectic integration of nature and nurture. *Child Development*, *81*, 6–22.

Sanders, L. D., Stevens, C., Coch, D., & Neville, H. J. (2006). Selective auditory attention in 3- to 5-year-old children: An event-related potential study. *Neuropsychologia*, *44*, 2126–2138.

Sheese, B. E., Voelker, P. M., Rothbart, M. K., & Posner, M. I. (2007). Parenting quality interacts with genetic variation in dopamine receptor D4 to influence temperament in early childhood. *Development and Psychopathology*, *19*, 1039–1046.

Shonkoff, J. P. (2010). Building a new biodevelopmental framework to guide the future of early childhood policy. *Child Development*, *81*, 357–367.

Silk, J. S., Shaw, D. S., Skuban, E. M., Oland, A. A., & Kovacs, M. (2006). Emotion regulation strategies in offspring of childhood-onset depressed mothers. *Journal of Child Psychology and Psychiatry*, *47*, 69–78.

Singer, W. (1995). Development and plasticity of cortical processing architectures. *Science*, *270*, 758–764.

Smith, A., Taylor, E., Brammer, M., Toone, B., & Rubia, K. (2006). Task-specific hypoactivation in prefrontal and temporoparietal brain regions during motor inhibition and task switching in medication-naive children and adolescents with attention deficit hyperactivity disorder. *American Journal of Psychiatry*, *163*, 1044–1051.

Spinrad, T. L., & Stifter, C. A. (2002). Maternal sensitivity and infant emotional reactivity: Concurrent and longitudinal relations. *Marriage & Family Review*, *34*, 243–263.

Sroufe, L., & Rutter, M. (1984). The domain of developmental psychopathology. *Child Development*, *55*, 17–29.

Stevens, C., Coch, D., Sanders, L., & Neville, H. (2008). Neural mechanisms of selective auditory attention are enhanced by computerized training: Electrophysiological evidence from language-impaired and typically developing children. *Brain Research*, *1205*, 55–69.

Stevens, C., Harn, B., Chard, D., Currin, J., Parisi, D., & Neville, H. (2013). Examining the role of attention and instruction in at-risk kindergarteners: Electrophysiological measures of selective auditory attention before and after an early literacy intervention. *Journal of Learning Disabilities*, *46*, 73–86.

Stevens, C., & Neville, H. (2013). Specificity of experiential effects in neurocognitive development. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences* (5th ed., pp. 2–21). Cambridge, MA: MIT Press.

Stevens, C., Sanders, L., & Neville, H. (2006). Neurophysiological evidence for selective auditory attention deficits in children with specific language impairment. *Brain Research*, *1111*, 143–152.

Striano, T., Reid, V. M., & Hoehl, S. (2006). Neural mechanisms of joint attention in infancy. *European Journal of Neuroscience*, *23*, 2819–2823. doi:10.1111/j.1460-9568.2006.04822.x

Stroganova, T. A., Orekhova, E. V., & Posikera, I. N. (1998). Externally and internally controlled attention in infants: An EEG study. *International Journal of Psychophysiology*, *30*, 339–351.

Stroganova, T. A., Orekhova, E. V., & Posikera, I. N. (1999). EEG alpha rhythm in infants. *Clinical Neurophysiology*, *110*, 997–1012.

Stroganova, T. A., & Posikera, I. N. (1993). Functional organisation of behavioural states in wakefulness during infancy (EEG study). In O. S. Adrianov (Ed.), *Brain and behaviour in infancy* (pp. 78–166). Moscow: IPRAN Press.

Swanson, J. M., Posner, M., Potkin, S. G., Bonforte, S., Youpa, D., & Cantwell, D. et al. (1991). Activating tasks for the study of visual–spatial attention in ADHD children: A cognitive anatomic approach. *Journal of Child Neurology*, *6*, S119–S127.

Swingler, M. M., Perry, N. B, Calkins, S. D., & Bell, M. A. (in press). Maternal sensitivity and infant response to frustration: The moderating role of EEG asymmetry. *Infant Behavior & Development*.

Thatcher, R. W. (1994). Cyclic cortical reorganization: Origins of human cognitive development. In G. Dawson & K. W. Fischer (Eds.), *Human behavior and the developing brain* (pp. 232–266). New York: Guilford Press.

Thatcher, R. W., Krause, P. J., & Hrybyk, M. M. (1986). Cortico-cortical associations and EEG coherence: A two-compartmental model. *Electroencephalography & Clinical Neurophysiology*, *64*, 123–143.

Thompson, R. A., & Goodvin, R. (2007). Taming the tempest in the teapot: Emotion regulation in toddlers. In C. A. Brownell & C. B. Kopp (Eds.), *Socioemotional development in the toddler years: Transitions and transformations* (pp. 320–341). New York: Guilford Press.

Thompson, R. A., Lewis, M. D., & Calkins, S. D. (2008). Reassessing emotion regulation. *Child Development Perspectives*, *2*, 124–131.

Wynn, K. (1992). Addition and subtraction by human infants. *Nature*, *358*, 749–750.

Yamada, Y., Stevens, C., Harn, B., Chard, D., & Neville, H. (2011). Emergence of the neural network for reading in five-year-old beginning readers of different levels of early literacy abilities: An fMRI study. *NeuroImage*, *57*, 704–713.

Yeung, N., Holroyd, C. B., & Cohen, J. D. (2005). ERP correlates of feedback and reward processing in the presence and absence of response choice. *Cerebral Cortex*, *15*, 535–544.