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The integration of cognition and emotion during infancy and early childhood: Regulatory processes associated with the development of working memory

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Abstract

This study was an attempt to integrate cognitive development (i.e., cognitive control) and emotional development (i.e., emotion regulation) in the first years of life. The construct of temperament was used to unify cognition and emotion because of its focus on attentional and regulatory behaviors. Children were seen at 8 months and $4\frac{1}{2}$-years of age in a study designed to examine the correlates of working memory development. Frontal brain electrical activity and temperament predicted working memory performance at 8 months. Similarly, frontal brain electrical activity, temperament, and language predicted working memory at age $4\frac{1}{2}$-years. Temperament in early childhood mediated the relation between infant temperament and early childhood working memory performance. These associated temperament characteristics highlight the value of early-learned regulatory and attentional behaviors and the impact of these early skills on later development.

Keywords: Infancy; Early childhood; Working memory; Temperament; EEG; Frontal lobe

1. Introduction

Research that integrates cognition and emotion is essential to any conceptualization of development. Emotion and cognition collaborate in the processing of information and the implementation of resultant behaviors (Cacioppo & Berntson, 1999), including those behaviors essential for attention and regulation. As such, emotions may be understood as organizers of behavior, essentially regulating a child's thinking, learning, and action. Likewise, emotions may be understood as being regulated by the child's thinking, learning, and action (Cole, Martin, & Dennis, 2004). Thus, cognition and emotion represent inseparable components of the developmental process (Bell & Wolfe, 2004).

The integration of cognitive and emotional development may be most successful within biologically-based developmental constructs that focus on neuropsychology and behavior. Perhaps one of the most compelling of these constructs is that of temperament. Rothbart and Bates (1998) defined temperament as biologically based individual differences in emotional reactivity and the emergence of self-regulation of that reactivity beginning later in the first year of life. The emergence of these early regulatory processes is facilitated by the development of attention and thus may have implications for cognitive development as well (Bush, Luu, & Posner, 2000; Fox, 1994; Ruff & Rothbart, 1996). Indeed, late in the first year of life infants also begin to exhibit cognitive regulation, or cognitive control, on certain working memory and inhibitory control tasks (Diamond, 1990; Diamond, Prevor, Callender, & Druin, 1997). Thus, even during infancy the development of both emotion regulation and higher order cognition may require the initial integration of some degree of controlled, effortful

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processing and response. Blair (2002) has suggested that cognition and emotion are likely integrated by school age. The purpose of this study was to explore the integration of emotion (i.e., temperament) and cognition (i.e., working memory and inhibitory control) during infancy and early childhood.

The relation between emotion regulation and cognitive control may be coordinated by common neural structures and circuitry. Both types of control have been associated to some degree with frontal-functioning. For example, patterns of asymmetries in brain electrical activity from frontal scalp locations have been linked with individual differences in temperamental emotion reactivity and regulation (Calkins, Fox, & Marshall, 1996; Fox, Henderson, Rubin, Calkins, & Schmidt, 2001). In the last half of the first year of life, infants who cry at maternal separation exhibit right frontal brain electrical activation during rest, whereas infants who do not cry exhibit left frontal activation during rest (Davidson & Fox, 1987; Fox, Calkins, & Bell, 1994). Right frontal activation also is associated with inhibited behaviors during infancy (Calkins et al., 1996), as well as during the preschool years (Fox et al., 2001). In contrast, Rothbart's temperament trait of surgency—defined by the temperament scales of approach, high-intensity pleasure, activity level, and low levels of shyness—is associated with left frontal activation in early childhood (Fox et al., 2001). It appears that the left frontal area is associated with approach situations and positive emotions and the right frontal area with withdrawal situations and negative emotions (Fox, 1994). Thus, frontal lobe activation asymmetries may be associated with varying levels of emotion regulation.

It is also the case that brain electrical activity from frontal scalp locations has been associated with individual differences in cognitive processing during infancy and early childhood, especially during cognitive processing that involves the skills of working memory and inhibitory control (WMIC). In the last half of the first year of life, infants with better performance on a spatial WMIC task have greater baseline levels of brain electrical activity at frontal scalp locations than infants with poorer performance on the task (Bell & Fox, 1992, 1997). When brain electrical activity is recorded during task performance, the better performing infants exhibit frontal brain electrical activity values that increase from baseline to task, whereas the infants with poorer performance have values that are comparable from baseline to task (Bell, 2001). Similar results have been reported on a verbal WMIC task with preschool children (Wolfe & Bell, 2004). Children with better performance have greater brain electrical activity at frontal scalp locations during both baseline and task than do children with low performance. Thus, frontal brain electrical activity may be associated with varying levels of cognitive control.

Posner recently proposed that the Anterior Attention System, involving frontal region cortical and subcortical components, regulates both cognitive and emotion processing (Bush et al., 2000). In adults, this system is characterized by effortful, controlled attentional processing to either cognitive or emotion stimuli. The functioning of this attention system begins to influence behavior during the later half of the first year of life (Ruff & Rothbart, 1996)—a time when advances are beginning to be made in the processes of cognitive inhibitory control (Bell & Adams, 1999; Diamond et al., 1997) and emotion regulation (Rothbart, Derryberry, & Posner, 1994; Ruff & Rothbart, 1996). Because it focuses on the emotion (i.e., temperament)-attention and cognitive-attention functions of the frontal cortex, the Anterior Attention System may be the functional system that has the ability to connect cognitive and emotion/temperament processes.

Indeed, researchers have begun to demonstrate some associations between temperament characteristics and cognitive processing. These investigations have focused on temperament dimensions that capture attentional-type (e.g., orienting, attention focusing, attention shifting) as well as regulatory-type (e.g., soothability, inhibitory control, approach-anticipation, anger-frustration) behaviors associated with both emotion and cognition (Rothbart & Bates, 1998). For example, positive associations have been found between scores on cognitive tasks, which include WMIC, and temperament measures of inhibitory control. Specifically, preschool children with high scores on WMIC measures also have high ratings of behavioral regulation by their parents and through laboratory observations (Davis, Bruce, & Gunnar, 2002; Gerardi-Caulton, 2000; Wolfe & Bell, 2004).

Negative associations also have been found between cognitive inhibitory control task scores and maternal ratings of regulatory-type behaviors, such as the approach-anticipation and the anger-frustration scales of the Children's Behavior Questionnaire (CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001). Specifically, children with higher scores on cognitive inhibitory control measures have lower ratings on the approach and anger dimensions of temperament (Gerardi-Caulton, 2000; Wolfe & Bell, 2004). This finding means that those children who do not perform well on tasks that require controlled or inhibitory processing also display more difficulty in the control or regulation of their anticipatory or frustration behaviors.

Our own cognitive neuroscience research program focuses on frontal lobe development in infants and young children. We have begun to investigate the relations between cognitive inhibitory control and emotion regulation using a multi-method approach including electrophysiological, behavioral, and parent-report data (Bell & Wolfe, 2004). Our cognitive focus is on working memory, and we are interested, specifically, in the construct of working memory as presented by Engle and colleagues (Engle, Kane, & Tuholski, 1999; Kane & Engle, 2002). Engle defines working memory as a system consisting of those long-term memory traces that are active above threshold. Included in this characterization of working memory are the procedures and skills necessary to achieve and maintain that above-threshold activation as well as a limited-capacity, controlled attention component. We chose this particular model of working memory for three reasons: (1) it includes the processes associated with inhibitory control (e.g., controlled attention), (2) it specifies the role of the dorsolateral prefrontal cortex in the process of working memory, and (3) it allows for individual differences in working memory based on both the capacity for controlled attention and differences in prefrontal functioning. With its inhibitory control component, the construct of working memory is well suited to our attempts at integrating cognitive control and emotion regulation from a developmental perspective.

Thus, the overall goal of this study was an attempt to integrate cognition and emotion. We wanted to determine whether temperament (i.e., emotion reactivity and emotion regulation) was associated with cognition (i.e., WMIC) during infancy and early childhood. From Rothbart and Posner's points of view (Bush et al., 2000; Rothbart & Bates, 1998; Ruff & Rothbart, 1996), the attentional and regulatory behaviors associated with temperament should be evident in cognitive processing. Therefore, we hypothesized that certain aspects of temperament—particularly those associated with attention and regulation—would show associations with cognition during infancy and childhood. Furthermore, we wanted to explore the notion that the temperament characteristics associated with cognition might be different during these two time periods. Rothbart and Bates (1998) purport that temperament, like any other phenomenon, develops and is influenced by environmental factors. Thus, temperament factors associated with cognitive processing during infancy may be very different than those related to cognition in early childhood.

In keeping with our cognitive neuroscience program of study, we also examined measures of brain electrical activity (i.e., the electroencephalogram—EEG) associated with cognitive processing. We were most interested in replicating our previous work demonstrating that individual difference in performance on WMIC tasks was correlated with individual differences in frontal EEG (e.g., Bell, 2001; Bell & Fox, 1992, 1997; Wolfe & Bell, 2004).

We also wanted to explore the possibility that *infant* temperament would influence *childhood* cognition. There is some evidence that infant temperament may be related to general cognitive development in early childhood. For example, Lewis (1993) found that distress at 3 months in a maternal separation–reunion paradigm predicted lower scores on a general cognitive index of memory, motor, and verbal abilities at age 4 years. With our specific interests in working memory and our conceptualization of emotion–cognition relations, we hypothesized that the attentional and regulatory aspects of infant temperament would predict working memory performance during early childhood.

Finally, it is difficult to conceive of regulatory aspects of development during early childhood without mention of linguistic development. There have been reports of correlations between language development and specific temperament dimensions like affect-extraversion (Slomkowski, Nelson, Dunn, & Plomin, 1992) and smiling/laughter (Dixon & Shore, 1997). The capacity of language to assist with regulatory aspects of development, especially those involving attentional control (Kopp, 1989), makes language a likely correlate of not only emotion development but also cognitive development. Therefore, we hypothesized that not only would language be associated with the level of cognitive development in early childhood, but also that infant temperament might predict childhood language performance. For example, are there specific characteristics in infancy that play a facilitative role toward linguistic competence in early childhood?

Based on the developmental literature and the theoretical assertions presented here, we have proposed a developmental model of the relations among electrophysiology, temperament, language, and WMIC from infancy to early childhood. This model is depicted in Fig. 1. Two sets of pathways have been previously supported: the ones from 8-month EEG and temperament to 8-month WMIC (Bell, under review), as well as the ones from $4\frac{1}{2}$-year EEG, temperament, and language to $4\frac{1}{2}$-year WMIC (Wolfe & Bell, 2004). We sought to replicate these findings; however, the main focus of our current analyses is the 8-month to $4\frac{1}{2}$-year pathways.

2. Method

2.1. Participants

Participants included 50 healthy 8-month-old infants (28 male, 22 female; 46 Caucasian, 1 African–American, 1 Asian–American, 1 Hispanic, 1 Native American) recruited from birth announcements placed in the local newspaper in Montgomery County, Virginia. Infants were born to parents with at least a high school diploma. College degrees were held by 79% of the mothers and 82% of the fathers. Mothers were approximately 29 years old (range 18–39)

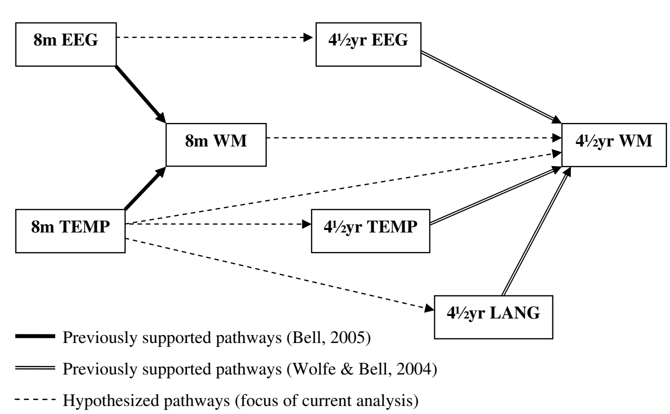

Fig. 1. Hypothesized model of the relations among electrophysiology, temperament, language, and working memory during infancy and early childhood.

and fathers were approximately 31 years old (range 20–47). All infants were full term and healthy at the time of testing. Infants were seen when they were between 8 and $8\frac{1}{2}$ months of age. Parents were paid for their infants' participation in the study.

The same families were contacted when the children had their 4-year-old birthdays and all participating children were $4\frac{1}{2}$-years of age at the second laboratory visit (range 52- to 56-months). Of the original 50 participant families, 43 were located and contacted; 27 of the 43 families were still in the local area. Of those 27 families, all but two agreed to return (one family too busy, one child too shy). This subgroup of 25 children from the original group of 50 infants was composed of Caucasian children. Children received a small gift for their participation in the study.

2.2. Procedures

2.2.1. EEG recordings at 8 months and $4\frac{1}{2}$-years

Upon arrival to the research laboratory, EEG electrodes were applied and one minute of baseline physiology was recorded. Electrodes remained on the scalp during the WMIC tasks. Although recordings were made from 16 left and right scalp sites [i.e., frontal pole (Fp1, Fp2); medial frontal (F3, F4); lateral frontal (F7, F8); central (C3, C4); anterior temporal (T3, T4); posterior temporal (T7, T8); parietal (P3, P4); and occipital (O1, O2)], the current analyses focus on the associations with the medial frontal region. All electrode sites were referenced to Cz during recording.

For the infant visit at 8 months of age, baseline EEG was recorded while the infant sat on his/her mother's lap and watched as a research assistant manipulated a toy containing brightly colored balls on top of the testing table, 1.1 m in front of the infant. This procedure quieted the infant and yielded minimal eye movements and gross motor movements, thus allowing the infant to tolerate the EEG cap for the recording. Mothers were instructed not talk to infants during the EEG recording. During the child visit at $4\frac{1}{2}$-years of age, physiological recordings were obtained during a baseline while the child watched a Sesame Street music video. While watching the video, the child sat in a chair with the parent seated beside and slightly behind the child. Immediately after baseline recordings at each age, the WMIC task was administered.

EEG was recorded using a stretch cap (Electro-Cap, Inc.) with electrodes in the 10/20 pattern (Jasper, 1958). After the cap was placed on the head, recommended procedures regarding EEG data collection with infants and young children were followed (Pivik et al., 1993). Specifically, a small amount of abrasive gel was placed into each recording site and the scalp gently rubbed. Next, conductive gel was placed in each site. Electrode impedances were measured and accepted if they were below 5 kΩ. Eye movements, digitized along with the EEG channels and used for subsequent artifact editing, were recorded using disposable electrodes. Electrodes were placed on the external canthus and the supra orbit of the right eye.

The electrical activity from each lead was amplified using separate SA Instrumentation Bioamps and band-passed from 1 to 100 Hz. Activity for each lead was displayed on the monitor of a 100 MHz acquisition computer. The EEG signal was digitized on-line at 512 samples per second for each channel so that the data were not affected by aliasing. The acquisition software was Snapshot-Snapstream (HEM Data Corp.) and the raw data were stored for later analyses.

EEG data were examined and analyzed using EEG Analysis System software developed by James Long Company. First, the data were re-referenced via software to an average reference configuration. Average referencing, in effect, weighted all the electrode sites equally and eliminated the need for a noncephalic reference. Active (F3, F4, etc.) to reference (Cz) electrode distances vary across the scalp. Without the re-referencing, power values at each active site may reflect interelectrode distance as much as electrical potential.

The average reference EEG data were artifact scored for eye movements using a peak-to-peak criterion of 100 μV or greater. Artifact associated with gross motor movements over 200 μV peak-to-peak was also scored. These artifact-scored epochs were eliminated from all subsequent analyses. The data were then analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-second width and 50% overlap. Power was computed for the 6 to 9 Hz frequency band. Infants at 8 months of age have a dominant frequency between 6 and 9 Hz (Bell, 1998; Bell & Fox, 1992) and this particular frequency band discriminates baseline EEG from task EEG (Bell, 2001), as well as correct from incorrect responses, during an infant working memory task (Bell, 2002). Similarly, this particular frequency band continues to be informative in early childhood because it remains a dominant frequency (Marshall, Bar-Haim, & Fox, 2002). For the current study, the power was expressed as mean square microvolts and the data were transformed using the natural log (ln) to normalize the distribution.

2.2.2. WMIC task at 8 months

The infant searched for a hidden toy by making an eye movement to one of two possible hiding locations. The task required the infant to update his/her memory of where the toy was hidden through a series of displacements and also required him/her to inhibit looking back toward a previously rewarded hiding place. The testing apparatus was a table measuring 90 cm (L) × 60 cm (W) × 75 cm (H) and the hiding sites were bright orange and blue plastic tubs that measured 17 cm in diameter and 11 cm deep. The infant sat on the parent's lap 1.1 m from the edge of the testing table as the experimenter manipulated a mechanical toy and hid it under one of the two plastic tubs located 17.5 cm on either side of the midline.

After the toy was hidden, the infant's gaze to the hiding site was broken and brought to midline by the experimenter calling the infant's name and asking, "Where's the toy?" (Bell, 2001). The direction of the infant's first eye movement after being brought to midline was scored as either correct or incorrect. A video camera was placed behind and above the experimenter's head and focused so as to maintain a close-up view of the infant's face. Because the infants were not allowed to manipulate the toys, the visual experience they received from the mechanical toy, as well as the smiles and praise ("Good job! You found it!") they received from the experimenter after an eye movement to the correct tub had to provide the impetus for the infants to continue searching for the toy. For an eye movement to the incorrect tub, the infants received a sigh and sad vocalizations from the experimenter ("Oh, no. It's not there.").

The pattern of toy placement was determined by the infant's performance, with side of hiding on the first trial randomized among infants. Two consecutive successful eye movements toward the same side (for example, toward the infant's right) resulted in the toy being hidden under the tub on the opposite side (toward the infant's left; i.e., Right-Right-Left). All infants received reversal trials. Regardless of whether the infant was successful on the reversal trial, new "same-side" trials commenced at the reversal site and continued until two consecutive successful eye movements were executed, which then initiated another reversal (i.e., L-L-R). Thus, flawless performance by an infant would result in this pattern of trials: R-R-L-L-L-R. In reality, most infants were not flawless in performance and some needed multiple same-side trials in order to achieve two consecutive successful eye movements prior to reversal trials (e.g., L-L-L-L-L-L-R-R-R-R-L). Assessment ceased when the infant made an eye movement toward the incorrect side in two reversal trials. The average number of trials (combining same-side and reversals) from which EEG data were collected was 18 per infant. The variable of interest was percentage of correct trials.

The experimenter essentially coded the infant's performance on-line (i.e., the pattern of toy placement was determined by the infant's performance). Reliability coding was done by a research assistant who viewed the videotape of the laboratory session. The percentage agreement between the coder and experimenter was 96%. Disagreements were discussed, with final determination of coding made by the second author.

An event marker was used in conjunction with the EEG recordings to mark which portions of the electrophysiological record were associated with the most cognitively demanding sections of the looking task. Thus, the task-related EEG started with the covering of the hiding site and non-hiding site with the orange and blue tubs, continued through the breaking of the infant's gaze and the infant's first eye movement toward one of the hiding sites, and stopped when the experimenter lifted a tub prior to giving the infant appropriate verbal feedback. The artifact-free EEG data from all trials (correct and incorrect) were used in these analyses.

2.2.3. *WMIC tasks at $4\frac{1}{2}$-years*

Two tasks were used to investigate the children's working memory and inhibitory control abilities: the day–night Stroop-like task and the yes–no task. Each of these tasks required the child to remember two rules and exhibit inhibitory control by performing a subdominant response. The day–night Stroop-like task has been used with children ages $3\frac{1}{2}$ to 7 years and is believed to involve the dorsolateral prefrontal cortex (Diamond et al., 1997). Children improve in performance on this task (i.e., increasing accuracy and decreasing reaction time) across the early childhood years (Diamond et al., 1997; Gerstadt, Hong, & Diamond, 1994). The yes–no task was created in our lab and is conceptually and procedurally similar to the day-night task (see Wolfe & Bell, 2004).

For the day–night Stroop-like task, the child was instructed to say "day" when shown a black card with a picture of a yellow moon and to say "night" when shown a white card with a picture of a yellow sun. The children were given two learning trials and 16 test trials: eight with the sun card and eight with the moon card arranged in a pseudorandom order. The total administration time was approximately 2 min. The percentage correct was calculated.

For the yes–no task, the child was instructed to say "yes" when the experimenter shook her head no and to say "no" when the experimenter nodded her head yes. We included this task to increase the length of the physiological data collection period during cognitive processing. The child was given two learning trials and then 16 test trials: eight with the experimenter nodding her head yes and eight with the experimenter shaking her head no in a pseudorandom sequence. Again, the total administration time was approximately 2 min, and the percentage correct was calculated.

Interrater reliability for these two tasks was accomplished from the videotapes of the laboratory sessions by the first author and a research assistant. The percentage of agreement between the two coders for the children's performance on the WMIC tasks was 98%. Disagreements in coding were discussed, with final determination of the scores made by the first author. The variable of interest was the average percentage of correct trials across both tasks.

EEG was recorded continuously during each of the two tasks. Computation of WMIC task EEG was accomplished by averaging the EEG power values from the day–night task and the yes–no task.

2.2.4. *Temperament measures at 8 months and $4\frac{1}{2}$-years*

The Infant Behavioral Questionnaire (IBQ; Rothbart, 1981) was used to examine parental perceptions of infant temperament. The questionnaire was mailed to the mothers one week prior to the laboratory appointment and collected upon arrival for the lab visit. This temperament questionnaire assesses parent ratings of infant behaviors that factor into the following six scales: activity level, distress to limitations, latency to approach, duration of orienting, smiling and laughter, and soothability.

The Children's Behavioral Questionnaire (CBQ; Rothbart et al., 2001) was used to examine parental perceptions of child temperament. The questionnaire was mailed to the mothers one week in advance and collected at the laboratory visit. There are 16 CBQ temperament scales: activity level, anger/frustration, approach/anticipation, attentional focusing, attentional shifting, discomfort, falling reactivity/soothability, fear, high intensity pleasure, impulsivity, inhibitory control, low intensity pleasure, perceptual sensitivity, sadness, shyness, and smiling/laughter.

2.2.5. Language measure at $4\frac{1}{2}$-years

The Peabody Picture Vocabulary Test-III (PPVT-III; Dunn & Dunn, 1997) was administered to the children to determine receptive vocabulary and verbal comprehension. The PPVT-III is a nationally standardized instrument. The variable of interest was age equivalency.

2.3. Analyses

At the $4\frac{1}{2}$-year assessment, there were complete EEG, WMIC task, language, and temperament questionnaire data for 20 children (11 boys, 9 girls). Reasons for missing data included refusing to wear the EEG cap (2 children), refusing the application of EEG gels (1 child), refusing to complete the WMIC tasks (1 child), and EEG equipment failure (1 child). Data from these 20 participants were used in all subsequent analyses. Also, when two of the children completed the infant assessment they did not wear the EEG cap and one of those cried and did not complete the infant WMIC task. Thus, 18 of these children contributed complete infant and child data to the analyses.

Using our initial, proposed model (Fig. 1) as a guide, the EEG, temperament, language, and WMIC data were analyzed using a series of multiple regression analyses in the path analytic tradition. We chose path analysis to assess our model in order to explore the validity of this causal model within a correlational research design (Pedhazur, 1997). Due to our limited sample size, we emphasize that the analyses are exploratory in nature; however, the longitudinal nature of these data makes these findings valuable, even within the acknowledged limitations of sample size.

3. Results

Data were collected at an 8-month visit (Bell, under review) and a $4\frac{1}{2}$-year visit (Wolfe & Bell, 2004). The structure of the results section includes three steps. First, predictors of WMIC performance at $4\frac{1}{2}$-years were examined. Second, predictors of WMIC performance at 8 months were examined. Finally, correlations between infant and child EEG, temperament, and WMIC were examined and infant predictors of early childhood WMIC performance and language were explored.[1]

3.1. Step one: $4\frac{1}{2}$-year analysis

Previously with these data, we focused on individual differences in WMIC and, thus, classified these children into high and low WMIC groups (Wolfe & Bell, 2004). We used these data to illustrate that frontal task-related EEG (specifically left medial frontal—F3), maternal report of temperament (approach/anticipation scale), and language (PPVT-III) predicted group membership. Our original analyses were done with step-wise hierarchical discriminant analysis. Together, these three variables were able to classify correctly 90 percent of the children into high and low WMIC groups.

In the current analysis, we attempted to replicate this finding using a different analytic technique, one that was more suitable for the current hypotheses. Thus, we selected the multiple regression procedure. Rather than using a categorical dependent variable for WMIC performance, we used the continuous variable, percentage of correct trials. To determine the value of these same three variables in predicting WMIC performance, a step-wise hierarchical regression was performed. Predictors were entered in the same order as in previous analyses (i.e., Wolfe & Bell, 2004). Order of entry was the PPVT-III score, the approach/anticipation scale of the CBQ, and left medial frontal task-related EEG (F3). Together, these early childhood predictors accounted for 65% of the variance in WMIC performance at $4\frac{1}{2}$-years (see Table 1; Fig. 2).

3.2. Step two: 8-month analysis

Previously, we showed with these infant data that WMIC performance during infancy can be predicted from electrophysiological and temperament measures (Bell, under review). Using the data from the original, larger group of infants (i.e., 50 participants), we classified the infants into high and low WMIC groups and demonstrated that group membership was predicted by measures of frontal EEG and maternal report of infant temperament (activity level, distress to limitations). We used discriminant function analyses and together these variables (when used in conjunction with heart period measures) were able to classify correctly 88% of the infants into high and low WMIC groups.

In the current analysis we attempted to replicate this finding using only the infants for whom there were also

[1] Although gender has been linked with two of our constructs of interest (i.e., linguistic development and self-regulation), with girls rated higher on these types of skills (e.g., Bono, 2003; Kochanska, Murray, & Harlan, 2000), no gender differences were found for these constructs in either of the previous studies of interest (i.e., Bell, under review; Wolfe & Bell, 2004). Therefore, gender was not considered a factor in any of the current analyses.

Table 1
Results of hierarchical regression analysis predicting working memory performance in early childhood from electrophysiology, temperament, and language receptivity

	β[a]	R	R^2	t	Sig.
Dependent variable: Working memory performance					
Predictors entered:					
Step 1: PPVT-III	.36	.59	.36	2.11	.05
Step 2: Approach (CBQ)	−.62	.73	.53	−3.35	.01
Step 3: EEG (F3)	.39	.81	.65	2.16	.05

[a] The values in the final equation, with all predictors entered.

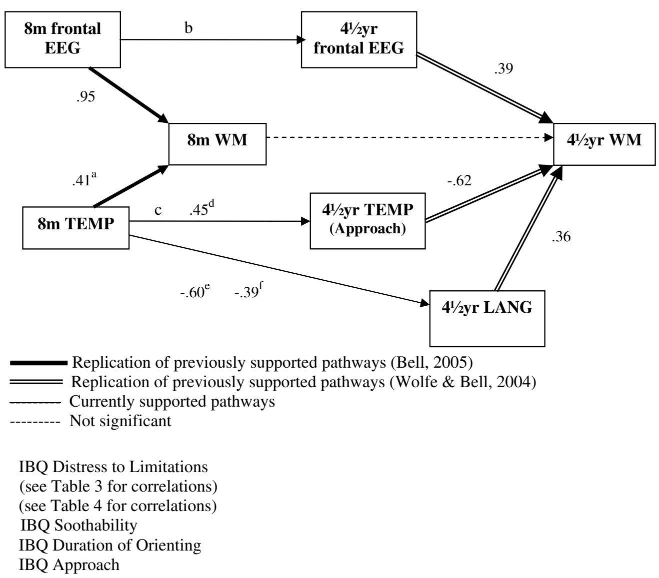

Fig. 2. Path diagram of the effects of infant and early childhood EEG and temperament on early childhood working memory performance. Path weights are standardized regression coefficients reported in the text and tables.

complete data at age $4\frac{1}{2}$-years (i.e., 18 infants). Similar to our analysis with the $4\frac{1}{2}$-year data, we selected the multiple regression procedure and used a continuous dependent variable, percentage of correct trials. The traditional regression procedure with the smaller sample did not replicate our findings with the larger original group, so we used an exploratory backward regression procedure that included the variables of interest from the original data set: the task-related frontal EEG (F3, F4) and the IBQ temperament measures (activity level, distress to limitations) as predictors. The most informative model revealed that 8-month WMIC performance in our small data set was predicted from medial frontal EEG (F4) and the IBQ temperament dimension of Distress to Limitations. Together, these two variables accounted for 39 percent of the variance in infant WMIC scores (see Table 2; and Fig. 2).

3.3. Step three: 8-month- to $4\frac{1}{2}$-year analyses

The third step of the analyses involved merging the infant and early childhood data sets. Previously, these data had only been examined at the individual age groups (infancy: Bell, under review; early childhood: Wolfe & Bell, 2004).

3.3.1. Infant and early childhood EEG

Initial analyses included examination of the associated infant and early childhood measures. As seen in Table 3, frontal infant EEG power values were correlated with frontal early childhood EEG power values. The negative correlations were the result of child power values being larger than infant power values. This negative correlation is likely the result of the infant EEG having its greatest power in the lower end of the 6–9 Hz frequency band and the child EEG having its greatest power in the upper end of this band. Marshall et al. (2002) noted that at central scalp locations the dominant frequencies are between 6 and 8 Hz from 5 to 10 months of age, whereas the dominant frequency at 4 years of age is at 9 Hz. The same developmental pattern may describe the EEG at frontal scalp locations.

3.3.2. Infant and early childhood temperament

As seen in Table 4, maternal report of infant temperament was correlated with maternal report of child temperament. Of special interest were the IBQ scales correlated with the CBQ approach/anticipation scale, as this was the CBQ scale that predicted WMIC performance in early childhood. IBQ correlates of CBQ approach/anticipation included activity level, duration of orienting, and soothability.

3.3.3. Infant and early childhood WMIC

Similarly, a correlation analysis was performed on the 8-month WMIC score and the $4\frac{1}{2}$-year WMIC score. The correlation was not significant but was in the hypothesized direction ($r = .24$, $p = .17$).

3.3.4. Infant temperament and child WMIC

After we demonstrated that infant/child EEG data were correlated, as were infant/child temperament data, our next task was to examine our hypothesized associations between infant temperament and early childhood WMIC and language. First, we examined the hypothesized pathway from 8-month temperament to $4\frac{1}{2}$-year WMIC. We proposed that the regulatory temperament factors from infancy would more likely be associated with early childhood

Table 2
Results of backward regression analysis predicting working memory performance in infancy from electrophysiology and temperament

	β^{a}	R	R^2	t	Sig.
Dependent variable: Working memory performance					
Independent variables: EEG (F3, F4); IBQ scales (activity level, distress to limitations)					
EEG (F3)	−.70	.62	.39	−1.33	.21
EEG (F4)	.95			1.80	.09
Distress to limitations (IBQ)	.47			2.17	.05

[a] The values with these three predictors entered.

Table 3
Correlations between infant frontal EEG and child frontal EEG

Infant frontal EEG	Child frontal EEG					
	Fp1	Fp2	F3	F4	F7	F8
Fp1	−.35***	−.35***	−.44*	−.56**	−.35***	−.41*
Fp2	—	—	—.41*	−.53**	—	−.35***
F3	—	—	—	—	—	—
F4	−.31***	—	—	−.31***	—	—
F7	—	—	—	—	—	—
F8	—	—	—	—	—	—

Note: $n = 18$, one-tailed test of significance.
* $p < .05$.
** $p < .01$.
*** $p < .10$.

Table 4
Correlations between Infant IBQ and Child CBQ maternal temperament ratings

CBQ Scales	IBQ Scales					
	Activity level	Latency to approach	Distress to limitations	Duration of orienting	Smiling & laughter	Soothability
Activity level	—	—	—	—	−.45*	.45*
Anger	—	—	.41*	—	—	—
Approach	.41*	—	—	.46*	—	.44*
Attentional focusing	—	—.32***	—	—	—	−.40***
Attention shifting	—	—	—	—	.49*	—
Discomfort	—	—	—	—	—	—
Falling reactivity/soothability	—	—	−.39*	—	—	.56**
Fear	—	—	—	—	—	.33***
High pleasure	—	—	—	—	—	.32***
Impulsivity	—	—	.32***	.33***	—	—
Inhibitory control	—	—	—	—	.37***	—
Low pleasure	−.38*	−.32***	—	.32***	.59**	—
Perceptual sensitivity	—	—	—	—	—	—
Sadness	—	—	.34***	.34***	—	—
Shyness	—	—	.35***	.38***	—	—
Smiling & laughter	—	—	—	—	—	—

Note: $n = 18$, one-tailed test of significance.
* $p < .05$.
** $p < .01$.
*** $p < .10$.

WMIC. To explore this possibility, we used the backward regression technique with all IBQ temperament dimensions entered as potential predictors of early childhood WMIC performance. After six iterations, only infant soothability remained as a potential predictor ($\beta = -.41$, $t = -1.922$, $p = .07$).

It seemed likely, however, that this infant temperament/early childhood WMIC association was mediated by early childhood temperament. We explored this possibility with two additional regression equations. Following the recommendations for assessing mediational relations (Baron & Kenny, 1986; Holmbeck, 2002), we also regressed infant temperament (soothability) on child temperament (approach/anticipation) and found that soothability predicted approach/anticipation ($\beta = .45$, $t = 2.11$, $p = .05$). We used approach/anticipation because this CBQ scale had predicted concurrent early childhood WMIC performance. Finally, the effect of infant soothability on child WMIC was nonsignificant when approach/anticipation was included in the regression ($\beta = -.21$, $t = -.94$, $p = .36$). Thus, child approach/anticipation mediated the relation between infant soothability and child WMIC (see Fig. 2).

3.3.5. *Infant temperament and child language*

We next examined the hypothesized pathway from 8-month temperament to $4\frac{1}{2}$-year language. Again, we used the exploratory backward regression technique with all IBQ temperament dimensions entered as potential predictors of early childhood language as measured by the PPVT-III. After five iterations, both infant approach/anticipation ($\beta = -.39$, $t = -1.95$, $p = .07$) and infant duration of orienting ($\beta = -.60$, $t = -2.97$, $p = .007$) remained as potential predictors (see Fig. 2).

4. Summary of Results

Findings are summarized in Fig. 2. Performance on the infant WMIC task was predicted from concurrent frontal EEG and maternal report of temperament, replicating our previous work (Bell, under review). Likewise, performance on the early childhood WMIC task was predicted from concurrent frontal EEG, maternal report of temperament, and language comprehension, replicating our previous work (Wolfe & Bell, 2004). Infant and child EEG, as well as infant and child temperament, were correlated. Infant and child WMIC performance was not. More importantly, infant temperament was a predictor of child language and child WMIC. Child temperament mediated the relation between infant temperament and child WMIC.

5. Discussion

Our overall goal was to integrate cognition and emotion in infancy and early childhood. We presented a model of relations among brain electrical activity, temperament, and cognition from infancy to early childhood and examined the predictive value of EEG and temperament for WMIC performance in early childhood. The exploratory nature of this project should be emphasized. Although our sample size for the initial infant group was respectable, half of the families had moved away from the local area by the time the children had reached early childhood. Therefore, we are cautious in our interpretations of the results. We point out, however, that the EEG findings were comparable to our previous work. That is, frontal EEG was correlated with WMIC performance (e.g., Bell, 2001; Bell & Fox, 1992). Furthermore, our EEG correlations from the infant to early childhood time period corroborate the work of Marshall et al. (2002), who demonstrated correlations of EEG values from infancy through age 4 with a longitudinal data set.

It should first be noted that performance on the infant WMIC task was not correlated with performance on the early childhood WMIC task. One explanation is that the operationalization of WMIC at both time periods was not comparable. Specifically, the infant task was a spatial WMIC task and the early childhood task required the integration of visual and verbal WMIC. A better test of the infant-to-child correlation might be to utilize a spatial WMIC task for the children as well.

Although we had hypothesized that infant temperament would predict WMIC performance in early childhood, we found that approach/anticipation at age $4\frac{1}{2}$ mediated the relation between 8-month Soothability and $4\frac{1}{2}$-year WMIC. In essence, an infant who is difficult to sooth at 8 months may be low on approach/anticipation behaviors at $4\frac{1}{2}$-years and thus more likely to perform well on WMIC tasks involving controlled, inhibitory processing. This intriguing finding raises two questions. First, why would there be a negative association between approach/anticipation behaviors and WMIC performance in early childhood? The approach/anticipation scale of the CBQ includes items that attempt to capture the regulatory abilities of young children. Parents are asked, for example, to rate their children on the following items: Gets so worked up before an exciting event that s/he has trouble sitting still; When s/he sees a toy s/he wants, gets very excited about getting it; Becomes very excited about upcoming television programs. It may be that these children who are low on approach/anticipation get just as enthusiastic about upcoming events, but they are able to focus their attentional and regulatory skills such that they are successful on the WMIC task. Others have reported a negative correlation between approach/anticipation and inhibitory control tasks (Davis et al., 2002). Thus, our findings mesh with previous reports of cognition–emotion research.

Secondly, how could approach/anticipation mediate the relation between infant soothability and preschool WMIC? In supporting infants during distress or fussiness, many parents attempt to soothe infants by distracting them with visual and other stimuli. These efforts may aid in the development of attentional skills that later are key in relieving distress (Ruff & Rothbart, 1996). These attentional skills may also contribute to the attentional and regulatory abilities associated with the Anterior Attention System and later complex cognition such as that required by WMIC tasks.

The age of an infant when distress and soothability are assessed may be important for predicting cognition. Lewis (1993) reported that 3-month distress in a maternal separation–reunion paradigm predicted lower scores on a general cognitive index. Later measures of distress (i.e., at 4–$5\frac{1}{2}$-months) did *not* predict cognitive competency at 4 years, however. It may be that at this slightly older time period infant soothability becomes a better predictor. Perhaps by 4 or 5 months of age, the initial distress of earlier infancy is abated somewhat, or parental intervention has aided in initial developmental of attentional skills hypothesized to be important to later cognition. Lewis (1993) suggested that there may be an age specific nature of temperament influences on cognitive outcomes. As temperament "develops" (Rothbart & Bates, 1998), its influence on other developmental processes develops as well.

The correlation between infant temperament and early childhood language also was negative. Low levels of Approach and Duration of Orienting during infancy were associated with higher levels of language in childhood. Bloom (1993, 1998) has proposed that neutral affect is more advantageous for language development. Both positive and negative affect may interfere with the cognitive capacity required for processing information. Although positive, surgent children are more likely to approach a situation and engage initially in language interactions, their outgoing behaviors may interfere with their capacity to take advantage of these linguistic experiences. The more affectively neutral child may have the time and energy to focus attention on the language and thus benefit more from the encounter. Furthermore, concurrent language and WMIC scores were positively correlated in this study. Adams and Gathercole (1995) also reported links between language and WMIC abilities, thus replicating the findings here.

With this longitudinal investigation, we have made an initial attempt to integrate cognition and emotion using the construct of temperament. By focusing on attentional and regulatory behaviors, we have shown that it may be possible to predict early childhood cognitive abilities not from infant cognitive performance, but from infant temperament characteristics. Although the analyses were exploratory, these tentative findings suggest the value of early-learned regulatory and attentional behaviors and the impact of these early skills on later development.

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