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# Working Memory and Inhibitory Control in Early Childhood: Contributions from Physiology, Temperament, and Language

**ABSTRACT:** This study examined the cognitive skills of working memory and inhibitory control (WMIC) in relation to physiological functioning, temperament, and language in early childhood. WMIC skills were assessed in twenty-five 4½-year-old children using the day–night Stroop-like task and the yes–no task; each task required the child to remember two rules and to inhibit a dominant response. Electroencephalogram (EEG) and heart period (HP) were recorded during baseline and WMIC tasks. An increase in 6- to 9-Hz EEG power from baseline to task was found for the medial frontal region. In addition, a decrease in HP (i.e., an increase in heart rate) was found from baseline to task. Associations were found between performance on the WMIC tasks and scales of the Children’s Behavioral Questionnaire (CBQ) related to the effortful control of behavior. The Peabody Picture Vocabulary Test-III (PPVT-III) distinguished between high and low WMIC performance. Results of a discriminant function analysis indicated that physiology, temperament, and language were able to correctly predict 90% of WMIC performance. © 2003 Wiley Periodicals, Inc. *Dev Psychobiol* 44: 68–83, 2004.

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Executive function skills, such as working memory, inhibitory control, planning, and attentional flexibility, are typically associated with the prefrontal cortex. Two of these skills, working memory and inhibitory control (WMIC), have been the focus of much behavioral (Diamond, Prevor, Callender, & Druin, 1997; Diamond & Taylor, 1996; Gerstadt, Hong, & Diamond, 1994; Welsh, Pennington, & Groisser, 1991), electrophysiological (Bell, 2001, 2002; Bell & Fox, 1992, 1997), and neuroscience research (Casey et al., 1997; Diamond, 1990a,b, 1991; Diamond & Goldman-Rakic, 1989;

Diamond, Zola-Morgan, & Squire, 1989). The results of these studies converge and suggest that the cortical and subcortical mechanisms associated with successful performance on WMIC tasks are developing during infancy and the early childhood years.

WMIC skill investigations typically include cognitive tasks that require the participant to hold some information in memory and to also inhibit a prepotent response. For example, a WMIC task for infants is Piaget’s (1954) classic A-not-B task, in which a toy is hidden in one of two wells (i.e., A or B) in full view of the infant and then the infant is encouraged to “find the toy.” After two correct reaches to Well A, the infant observes the toy being hidden in the opposite well, and the infant is again encouraged to find the toy. Infants younger than 8 months have the tendency to reach back to Well A, not Well B, even though they observed the toy being hidden in B. Research and theory about this phenomenon maintain that successful performance on this task (i.e., reaching to B) requires both cognitive skills of working memory and inhibitory

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control; further, the dorsolateral prefrontal cortex has been associated with the integration of these two skills (Diamond, 1990a,b; Diamond et al., 1997).

A WMIC task that has been used with children from 3½ to 7 years of age is the day–night Stroop-like task (Diamond & Taylor, 1996; Diamond et al., 1997). In this task, the children are instructed to say “day” when they are shown a nighttime scene and are instructed to say “night” when shown a daytime scene. The children, therefore, are required to remember two rules (i.e., the instructed responses for each picture stimulus) and to also inhibit a dominant response (i.e., the tendency to label the picture correctly). Because successful performance on the day–night Stroop-like task appears to require the same cognitive skills as does Piaget’s A-not-B task (i.e., working memory and inhibitory control), it is hypothesized to involve prefrontal functioning as well. Further, individual differences regarding the development of WMIC skills in infancy and early childhood have been attributed to differences in physiology (Bell, 2001), temperament (Gerardi-Caulton, 2000), and language development (Hughes, 1998).

## PHYSIOLOGY

### EEG

Physiological research indicates that the frontal cortex is active and maturing during infancy (Bell, 2001; Chugani, 1994). It has been demonstrated that the maturation of the frontal cortical region in infants—marked by increasing baseline frontal electroencephalographic (EEG) power values—is associated with increased performance on Piaget’s classic A-not-B task (Bell & Fox, 1992, 1997). Higher occipital EEG power values during baseline also are associated with better task performance (Bell & Fox, 1992, 1997).

Development of a looking version of the A-not-B task (see Bell & Adams, 1999) has allowed for task-related EEG recordings during infant working memory performance (Bell, 2001, 2002, 2003). As with the classic Piagetian reaching version of the task, infants “search” for a hidden toy. The only difference is the response modality: a look as opposed to a reach. This oculomotor response eliminates gross motor artifact and allows the recording of task-related EEG. Recent studies have shown an increase in frontal as well as posterior EEG power values from baseline to task for high-performing infants, those who were successful on the reversal (or “B”) trials. Infants who erred on the reversal trials demonstrated less developed WMIC skills and showed no change in EEG power values from baseline to task (Bell, 2001). Infants show a similar pattern of increase in EEG power

values from baseline to task during sustained attention (Orehova, Stroganova, & Posikera, 1999; Stroganova, Orehova, & Posikera, 1998, 1999) and cortical inhibition tasks (Orehova, Stroganova, & Posikera, 2001) as well.

Although baseline to task increases in EEG power values have been associated with the development of WMIC in infants, no research to date has examined this specific relation in the early childhood years—a time when many advances (e.g., accuracy and speed) are being made in inhibitory control abilities (Diamond & Taylor, 1996; Diamond et al., 1997; Gerstadt et al., 1994; Luciana & Nelson, 1998; Welsh et al., 1991; but see Debeus, 2000, for research with young children using EEG coherence measures and a working memory task). However, *fMRI* data have been collected with 7- and 8-year-olds using a go, no-go inhibitory control reaction-time task that induced conflict between responding and withholding a response (Casey et al., 1995; Casey et al., 1997; Durston et al., 2002). This work has shown cortical activation along the frontal midline—a notably different activation pattern than was found in the infant EEG research, where most scalp locations were indicated. EEG replication of this *fMRI* working memory activation pattern in young children is needed and would validate EEG as a measure of this phenomenon in young children, endorsing further EEG research with these constructs.

The first goal of this study was to measure baseline and WMIC task brain electrical activity in young children and specifically to answer the following questions: (a) Can we replicate the infant EEG results with young children? That is, will there be an increase in EEG power from baseline to WMIC task for young children? If so, will this increase be found for multiple regions (i.e., frontal and posterior) as with infants or will this increase be specific to the frontal region as with the *fMRI* work with older children? (b) Will individual differences in WMIC task performance be associated with differences in baseline and task-related EEG? Specifically, as with the infant EEG work, will children who are successful on WMIC tasks exhibit greater EEG power values than children who are less successful on these tasks?

### Heart Period

Heart period (HP) has long been used to assess physiological changes associated with cognitive processing in infants and young children (see Fox, Schmidt, & Henderson, 2000, for a review). HP and its inverse, heart rate (HR), are the most frequently used measures of attentional state (e.g., Casey & Richards, 1991; Richards & Casey, 1991), and sustained attention may be similar to working memory during infancy and early childhood (Diamond et al., 1997). One attention-related

pattern of HR occurs during a stressor, such as a challenging mental task, and is associated with an increase in HR or a decrease in HP (Manuck, Kasprovicz, & Muldoon, 1990). This pattern is likely to emerge near the end of the first year of life in association with the development of the anterior attention system (Ruff & Rothbart, 1996). Thus, this pattern should be well developed and evident during mental stressors during early childhood.

Thus, the second goal of this study was to examine the changes in HP from baseline to WMIC task in the children and to answer the following questions: (a) Because the tasks in this study require intentional, controlled processing in preschoolers, will there be a decrease in HP (i.e., increase in HR) from baseline to task? (b) Will this decrease in HP be specific to the high WMIC performance group?

## TEMPERAMENT

In an attempt to synthesize cognitive and socioemotional development within a biologically based developmental model, there has been a general interest in linking temperament and cognition (e.g., Blair, 2002; Bush, Luu, & Posner, 2000; Fox, 1994; Rothbart & Derryberry, 1981; Rothbart, Derryberry, & Posner, 1994; Ruff & Rothbart, 1996). Further, an overlap between the two constructs has been empirically noted (Andersson & Sommerfelt, 1999; Bauer, Burch, & Kleinknecht, 2002; Halpern, Garcia Coll, Meyer, & Bendersky, 2001; Kubicek, Emde, & Schmitz, 2001; Lewis, 1993; Martin & Holbrook, 1985; Matheny, 1989; Mevarech, 1985; Miceli, Whitman, Borkowski, Braungart-Rieker, & Mitchell, 1998; Newman, Noel, Chen, & Matsopoulos, 1998; Palisin, 1986).

Rothbart and Bates (1998) defined temperament as biologically based individual differences in emotional, motor, and attentional reactivity and self-regulation. Research specifically adopting Rothbart's theoretical orientation and measures of temperament also has demonstrated an association between temperament characteristics and cognitive processing (Ahadi, Rothbart, & Ye, 1993; Gerardi-Caulton, 2000; Gerardi, Rothbart, Posner, & Kepler, 1996; Kochanska, Murray, & Coy, 1997; Kochanska, Murray, & Harlan, 2000; Miceli et al., 1998; Rothbart, 1988; Ruff & Rothbart, 1996). For example, employing the duration fixation paradigm that has been associated with later cognitive abilities (Colombo, 1993), Rothbart (1988) found a negative relation between duration of looking and laboratory measures of smiling and laughing in infants.

One of Rothbart's childhood temperament constructs of interest to the current study is effortful control—one

of three broad factors ascertained from the Children's Behavior Questionnaire (CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001) defined by the scales of inhibitory control (i.e., the capacity to plan and to suppress inappropriate approach responses under instructions or in novel or uncertain situations), attentional focusing (i.e., the tendency to maintain attentional focus upon task-related channels), low-intensity pleasure (i.e., amount of pleasure or enjoyment related to situations involving low stimulus intensity, rate, complexity, novelty, and incongruity), and perceptual sensitivity (i.e., the amount of detection of slight, low-intensity stimuli from the external environment). Effortful control involves the control of action combined with the control of attention (Ruff & Rothbart, 1996) and has been specifically defined as the ability to suppress a dominant response to perform a subdominant response (Kochanska et al., 2000; Rothbart & Ahadi, 1994; Rothbart & Bates, 1998). Further, due to its relation to high levels of attentional control, effortful control has been associated with emotion regulation (Rothbart, Ahadi, & Hershey, 1994) and lower levels of negative affect in particular (Derryberry & Rothbart, 1998; Eisenberg et al., 1993; Mischel, 1983). Effortful control is conceptually similar to the cognitive inhibitory control component of the WMIC skill coupling described by Diamond (1985) and, likewise, has been associated with prefrontal function (Derryberry & Rothbart, 1997; Posner & Rothbart, 2000; Rothbart et al., 1994). As such, it is likely that the developmental trajectories of effortful control and cognitive inhibitory control include some common or overlapping pathways—pathways that are likely influenced by developing attention systems.

The development of the anterior attention network, or the self-regulatory attention system (Rothbart & Bates, 1998), and particularly the anterior cingulate gyrus with projections to the frontal cortex (Bush et al., 1998; Bush et al., 2000; Posner & DiGirolamo, 1998; Posner, Rothbart, & Harman, 1994), may be a link between cognitive inhibitory control and effortful control abilities (Rothbart et al., 1994; Rothbart & Posner, 2001; Ruff & Rothbart, 1996). There is evidence that the processes associated with the anterior attention network may be involved in the regulation of both cognitive processing and emotional reactivity (Bush et al., 2000). In the developmental literature, however, these associations remain unsubstantiated because of the lack of research exploring these links (Davis, Bruce, & Gunnar, 2002).

There have been two published studies examining associations between cognitive processes associated with the anterior attention system and temperament. First, it has been reported that 3-year-old children who are successful on tasks involving spatial conflict score high on behavioral measures of inhibitory control—or the ability to exert control over their behavior (Gerardi-Caulton,

2000). These children also are rated highly by their parents on the CBQ temperament scales of focused attention, perceptual sensitivity, inhibitory control, and low sensitivity pleasure (i.e., likely to get pleasure from low-intensity stimulation). Note that these four scales are the subscales comprising the aforementioned effortful control factor. These children also have low ratings on the CBQ scale of anger/frustration, conceivably because they are able to regulate their anger or frustration by using their effortful control skills.

In a second study including 6-year-old children, Davis et al. (2002) sought a relation between CBQ parental ratings of inhibitory control and performance on a neuropsychological inhibitory control task developed by Casey et al. (1997)—a task that has been shown to involve prefrontal systems including the anterior cingulate cortex. As expected, performance on the task was positively related to maternal temperament ratings of inhibitory control. This finding is significant for the current study and supports the legitimacy of using parent report for these constructs.

A third goal of this study, therefore, was to investigate any relations between WMIC skills and a few CBQ temperament scales with a particular interest in the four subscales of the effortful control factor (i.e., attention focusing, inhibitory control, low sensitivity pleasure, and perceptual sensitivity) as well as the anger/frustration measure included by Gerardi-Caulton (2000). (a) Will we find similar associations between these temperament scales and our WMIC measures? (b) Specifically, will those children who perform well on the WMIC tasks also receive higher parental ratings of the ability to control their behavior?

## LANGUAGE

Similarly, theorists have suggested an association between temperament qualities and the development of language. The influence of temperament characteristics on the development of language abilities has been reported (Dixon & Shore, 1997; Dixon & Smith, 2000; Kubicek et al., 2001; Slomkowski, Nelson, Dunn, & Plomin, 1992). Specifically, temperament traits, such as affect-extraversion (i.e., high interest in persons, high cooperativeness, low fearfulness, and high happiness), at 2 years of age have been positively related to several language measures at 7 years (Slomkowski et al., 1992). Smiling-laughter and duration of orienting at 13 months has been associated with language style at 21 months (Dixon & Shore, 1997).

Further, with regard to the influence of linguistic and cognitive aspects of development on temperament characteristics and behaviors, it has been suggested that the development of language along with the continued

development of the frontal cortex may underlie further advances in voluntary control of behavior and action (Ruff & Rothbart, 1996). In fact, an association between language and the self-regulatory aspects of development, especially those that involve higher level attentional control, has been reported (Kaler & Kopp, 1990; Kopp, 1989).

Finally, there appears to be an association between memory and language. For example, recognition memory scores at 7 months have been shown to be correlated with language comprehension and expression at 2½, 3, and 4 years of age and with verbal IQ at age 5 (Rose, Feldman, Wallace, & Cohen, 1991). Likewise, phonological working memory scores of 3- to 4-year-old children have been associated with speech production. Specifically, children with high working-memory abilities produce more complex spoken language than children with low working-memory abilities (Adams & Gathercole, 1995).

Thus, the fourth goal of this study was to investigate (a) the potential relation between WMIC skills and language ability. (b) Specifically, we wanted to know if children who are more successful on the WMIC tasks also would score higher on the language receptivity assessment.

## A SUMMARY OF THE RESEARCH QUESTIONS

The previous review suggests that physiology, temperament, and language may be associated with the development of WMIC skills. This study was designed to answer the following research questions.

### Physiology

First, can we replicate the infant EEG results with young children? More specifically, will there be an increase in EEG power from baseline to WMIC task? If so, will this increase be found for multiple regions (i.e., frontal and posterior) as with infants or will this increase be specific to the frontal region as with the fMRI work with older children?

Second, will individual differences in WMIC task performance be associated with differences in baseline and task related EEG? Specifically, as with the infant EEG work, will children who are successful on WMIC tasks exhibit greater EEG power values than children who are less successful on these tasks?

Third, because the tasks in this study required intentional, controlled processing in preschoolers, will there be a decrease in HP (i.e., increase in HR) from baseline to task? Will this decrease in HP be specific to the high-performing WMIC children?

## Temperament

Will WMIC skills be positively associated with the temperament dimension of effortful control—attention focusing, inhibitory control, low sensitivity pleasure, and perceptual sensitivity? Will other temperament dimensions, specifically anger/frustration, be related to WMIC task performance?

## Language

Will there be a relation between WMIC skills and language? Will children who are successful on the WMIC tasks score higher on the language assessment?

## Collective Contributions to WMIC

The final research question of this study is how all of these facets of development—physiology, temperament, and language—work together to discriminate between high and low WMIC task performance.

## METHOD

### Participants

Participants were 4½-year-old children who had participated in a research study on infant WMIC when they were 8 months old.<sup>1</sup> For the 8-month-old study, 50 healthy, full-term infants and their parents were recruited from birth announcements placed in the local newspapers. In this follow-up study, parents were contacted by telephone after the children had their 4-year-old birthday; as a result, all children were 4½ years of age at the laboratory visit (range 52–56 months). Of the original 50 participant families, 43 were located and contacted; however, only 27 families were still in the local area. Of those, 25 agreed to return to the lab for a follow-up visit, and two declined the invitation (one family too busy and one child too shy). Further, due to children refusing to wear the EEG cap (2), refusing the application of EEG gels (1), refusing to complete the WMIC tasks (1), and equipment failure (1), complete EEG and behavioral data were collected for 20 children (11 boys and 9 girls). Data from these 20 participants were used in all subsequent analyses. This subgroup was composed of Caucasian children of right-handed parents. The majority of children were second born (30% first, 55% second, 15% third or fourth) with parents who both had a college education (68.75%). Table 1 includes additional demographic information.

Incidentally, because a few children refused some procedures—a self-selection maneuver that might be related to temperament—and were thereby excluded from further analyses, a series of univariate analyses of variance (ANOVAs) were performed to determine if those children differed significantly on any variable of interest (i.e., WMIC performance, language

**Table 1. Demographic Information**

Mean age (in months)	54
Mean birth weight [in lb (oz)]	7(33)
Mean number of siblings	1.3
Percent of participants who were male	55
Percent of participants who were European Caucasian	100
Percent of right-handed parents	100
Mean age of mother at child's birth (in years)	30.60
Mean education level of mother (in years)	15.60
Mean age of father at child's birth (in years)	31.60
Mean education level of father (in years)	16.05

scores, or temperament ratings) from those children who participated in all procedures. Results indicated that as a group, the children who refused some procedures were no different than the other participants on WMIC task performance,  $F = .024$ ,  $p > .05$ , language scores,  $F = 3.75$ ,  $p > .05$ , and all CBQ temperament scales,  $F_s < 4.17$ ,  $p_s > .05$ , except for the attention focusing scale,  $F = 4.52$ ,  $p < .05$  (Refused  $M = 4.00$ ,  $SD = .92$ ; Participated  $M = 4.83$ ,  $SD = .68$ ), on which those children who completed all procedures were rated higher in attention focusing behaviors by their mothers than those children who refused some procedures.

### Procedures

Upon arrival at the lab, participants and their parents were greeted, procedures were described, permission was obtained from the parents, and verbal assent was obtained from the children. EEG, HP, and EOG electrodes were then applied as the child was entertained by a research assistant and an age-appropriate computer game. Physiological recordings were obtained during a 1-min baseline condition while the child watched a Sesame Street music video and during two WMIC tasks described later. All physiological recordings were obtained while the child sat in a chair with the parent seated beside and slightly behind the child. The second segment of the visit consisted of four temperament (i.e., effortful control) tasks and a language receptivity/comprehension assessment. Physiological data were not obtained during these later tasks due to the gross motor movement required by them and the potential introduction of artifact into the data.

**Physiological Recordings.** EEG was recorded using an Electro-Cap from eight left and eight right scalp sites: Frontal pole (Fp1, Fp2), medial frontal (F3, F4), lateral frontal (F7, F8), central (C3, C4), anterior temporal (T3, T4), posterior temporal (T5, T6), parietal (P3, P4), and occipital (O1, O2), referenced to Cz. NuPrep and EEG Gel conductor were inserted into each recording site and the scalp lightly rubbed. Electrode impedances were measured and accepted if they were below 5,000 ohms. The electrical activity from each lead was amplified using separate SA Instrumentation Bioamps, band passed from 0.1 to 100 Hz, and digitized online at 512 samples per second to prevent aliasing. Activity for each lead was displayed on a

<sup>1</sup>This article reports on the 4½-year data only. See Bell (2003) for a report of the 8-month data and Wolfe and Bell (2003) for a report of the 8-month to 4-year developmental patterns.

Pentium computer using Snap/Shot acquisition software.<sup>2</sup> EOG was recorded using disposable gel-filled electrodes placed on the external canthus and supra orbit of the left eye. EOG was digitized along with the EEG and used for later artifact editing of the EEG recording.

The EEG data were examined and analyzed using EEG Analysis System software.<sup>3</sup> First, the data were rereferenced via software to an average reference configuration and then artifact scored for eye movements (using EOG as a guide) and gross motor and muscle movements through visual examination. Approximately 40% of the EEG data (including both baseline and task epochs) was artifact-rejected and was eliminated from all subsequent analyses. The amount of artifact-scored data was unrelated to the CBQ temperament dimensions,  $r_s < .44$ ,  $p_s > .05$ , and to the cognitive performance groups,  $F_s < 1.760$ ,  $p_s > .05$ . The remaining artifact-free data were then analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-s width and 50% overlap. Power was computed for the 6- to 9-Hz frequency band, the dominant frequency for infants and preschool children (Marshall, Bar-Haim, & Fox, 2002). The power was expressed as mean square microvolts, and the data transformed using the natural log (ln) to normalize the distribution.

HP was recorded at the same time using two small, disposable gel-filled electrodes placed on the left collarbone and the lower right rib cage. This placement of electrodes on the torso is less affected by body movements compared to the traditional limb placement and allows for prominent r-wave detection (Stern, Ray, & Quijley, 2001). In fact, only 5% of the HP data was artifact-rejected and eliminated from further analyses. Again, the amount of artifact-rejected data was unrelated to the temperament dimensions,  $r_s < .17$ ,  $p_s > .05$ , and to the cognitive performance group,  $F = .014$ ,  $p = .906$ .

**WMIC Tasks.** 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 perform a subdominant response. As previously mentioned, the day-night Stroop-like task has been used in the developmental literature with children ages  $3\frac{1}{2}$  to 7 years and is believed to involve the dorsolateral prefrontal cortex (Diamond & Taylor, 1996; Diamond et al., 1997; Gerstadt et al., 1994). Diamond and Taylor (1996) noted an improvement in performance on this task (i.e., increasing accuracy and decreasing reaction time) across the early childhood years. The yes-no task was created in our lab and is conceptually and procedurally similar to the day-night task.

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, then 16 test trials were administered, 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.<sup>4</sup>

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 WMIC 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 20 children and their performance on the cognitive tasks was 98%. The disagreements in coding were discussed, with final determination of the scores made by the first author.

**Temperament-Laboratory Measures.** The following tasks were used to assess the child's effortful control abilities: the tongue task, the dinky toys task, the wrapped-gift task, and the bow task. The administration and coding procedures for each of these tasks was taken from Kochanska et al. (2000).

The tongue task challenged the child to hold an m&m or Goldfish cracker on his or her tongue without chewing it for increasing intervals of time (four trials with delays of 10, 20, 30, and 15 s). The latency to swallow or chew the candy was coded. Reliability was 100% (all scores within 1 s). The scores were averaged across the four trials.

The dinky toys task required the child to choose one prize from a tray full of toys without touching or pointing to the toy. The child was further instructed to put his or her hands on his or her knees and to "use his(her) words." The child's behavior was coded on the following scale: 0 (*grabs a toy*), 1 (*touches toy*), 2 (*points to a toy, but does not touch*), 3 (*removes hands from knees, but does not point*), or 4 (*hands immobile on knees*). Kappa for pointing or touching was .93.

For the wrapped-gift task, the experimenter wrapped a gift for the child while the child was in the room. The child was asked to stand with his or her back to the experimenter and not to peek while the gift was being wrapped (60 s). During the wrapping time, the extent of the child's peeking and turning was scored on the following scale: 1 (*turns around and continues to peek*), 2 (*turns around, peeks, and then turns back around*), 3 (*peeks over shoulder*), 4 (*turns toward peeking, but does not*), and 5 (*does not peek*). The latencies to peek and turn were scored. Kappa for peeking was .90, and 90% of the latencies were within 1 s.

After the gift was wrapped, the experimenter put the gift on the table and had the child sit at the table. Before leaving "to get a bow," the experimenter asked the child not to touch the gift until

<sup>2</sup>Commercial software available from HEM Data Corporation, 17336, West Twelve Mile Road, Southfield, Michigan 48076. Phone: (313) 559-5607.

<sup>3</sup>Commercial software available from James Long Company, 333 Kasson Drive, Caroga Lake, New York 12032-5139. Phone: (518) 835-3734.

<sup>4</sup>Similar to the WMIC task scoring by Diamond and colleagues, response latencies were calculated for the day-night and yes-no tasks. However, no associations were found between response time and performance on the respective tasks,  $r_s < .20$ ,  $p_s > .05$ .

she returned (180 s). During the wait-for-the-bow time, the children were given a 1 (*opens gift*), 2 (*lifts gift*), 3 (*touches gift*), or a 4 (*does not touch*) based on the extent of their touching or lifting the package. Latencies to touch, open, and lift the gift were also scored. Kappa for touching or lifting was 1.00; 85% of latencies were within 1 s, and 90% were within 4 s. Disagreements in coding were discussed, with the final determination of scores made by the first author.

**Temperament–Parent Report.** The CBQ (Rothbart et al., 2001) was used to examine parental perceptions of child temperament. The questionnaire was mailed to the parents 1 week in advance and collected at the laboratory visit. Although all CBQ temperament scales were utilized, the scales of particular interest were attention focusing, inhibitory control, low sensitivity pleasure, perceptual sensitivity, and anger/frustration.

**Language Measure.** The Peabody Picture Vocabulary Test-III (PPVT-III; Dunn & Dunn, 1997) was administered to the children individually to determine receptive vocabulary and verbal comprehension. The PPVT-III is a nationally standardized instrument; the children's standardized scores were used in all analyses.

## RESULTS

Children were divided into two WMIC groups based on their performance on the two working memory and inhibitory control tasks (i.e., the day–night Stroop-like task and the yes–no task).<sup>5</sup> For each child, the percentage correct was calculated for each of the two tasks and then averaged to get one WMIC score. Children were then grouped into high and low WMIC performance groups by a median split categorization (Median = 72.9167). Using this classification, 12 children were considered high performers ( $M = 81.37$ ,  $SD = 8.53$ ), and eight children were considered low performers ( $M = 63.51$ ,  $SD = 8.90$ ). The unequal group sizes were a result of 3 children scoring at the median and the decision to place them in the high-performing group. The child's age was unrelated to any WMIC, temperament, or language variable,  $r_s < .25$ ,  $p_s > .05$ . Means for the WMIC, temperament, and language measures are in Table 2.

<sup>5</sup>Diamond and Taylor (1996) compared the children's performance on the first four trials of the day–night task to the last four trials of the task and found that the children performed significantly better on the first four trials. We also performed these analyses and arrived at the same conclusion: On both the day–night and yes–no tasks, children perform better on the first four trials than the last four trials, day–night:  $t = 2.55$ ,  $p = .02$ , first four:  $M = 80.00$ ,  $SD = 20.84$ , last four:  $M = 56.25$ ,  $SD = 34.29$ ; yes–no:  $t = 2.94$ ,  $p = .008$ , first four:  $M = 88.75$ ,  $SD = 20.64$ , last four:  $M = 72.50$ ,  $SD = 22.79$ . The finding lends additional support to the notion that 4½-year-old children cannot maintain a high level of performance across all 16 trials.

## EEG and WMIC

The EEG analysis tested for regional power differences between baseline and task and for WMIC performance group differences in power values. The EEG data for both WMIC tasks were combined, and the EEG power values for day–night and yes–no were weighted by the amount of time EEG was collected for each task. A repeated measures MANOVA was done on the ln EEG power values. The within-subjects factors were condition (i.e., baseline and task), region (i.e., frontal pole, medial frontal, lateral frontal, central, anterior temporal, posterior temporal, parietal, and occipital), and hemisphere (i.e., left and right). The between-subjects factor was WMIC performance group (i.e., low and high).

This analysis yielded a main effect for region,  $F(7, 12) = 12.246$ ,  $p < .001$ . This was superseded by Condition  $\times$  Region,  $F(7, 12) = 8.449$ ,  $p < .001$ , and Region  $\times$  Hemisphere,  $F(7, 12) = 4.818$ ,  $p = .009$ , interactions. There also was a trend toward a WMIC group effect,  $F(1, 18) = 3.899$ ,  $p = .064$ .

To aid interpretation of the interaction between condition and region and the interaction between region and hemisphere, separate MANOVAs were performed on the ln EEG power values for each region. This analysis also allowed for post hoc examination of the between-group trend as well. Although the WMIC group effect from the overall MANOVA was not significant (i.e.,  $p = .064$ ), we had specific hypotheses about the medial frontal region and chose to explore potential group differences at the other regions as well. For the MANOVAs for each region, WMIC performance group (i.e., low and high) was the between-subjects factor and condition (i.e., baseline and task) and hemisphere (i.e., left and right) were the within-subjects factors. These later analyses revealed no effects or interactions for the frontal pole, parietal, or occipital regions,  $F_s < 1.68$ ,  $p_s > .05$ .

**Medial Frontal (F3, F4).** There were main effects for condition,  $F(1, 18) = 6.891$ ,  $p = .017$ , with all children exhibiting greater EEG power values during task than during baseline, and hemisphere,  $F(1, 18) = 7.319$ ,  $p = .014$ , with greater EEG power at right (F4) than left (F3). There was a group main effect,  $F(1, 18) = 5.248$ ,  $p = .034$ , with the high-performance group showing greater overall EEG power values than the low-performance group (see Figure 1).

**Lateral Frontal (F7, F8).** There was a group main effect,  $F(1, 18) = 5.748$ ,  $p = .028$ , with the high-performance group showing greater overall EEG power values than the low-performance group (see Figure 2).

**Central (C3, C4).** There was a main effect for hemisphere,  $F(1, 18) = 6.543$ ,  $p = .020$ , with greater EEG

**Table 2.** Descriptive Statistics for WMIC, Temperament, and Language Measures

	Mean	SD	Range
WMIC Tasks	74.22	12.32	47.92–97.92
Temperament laboratory measures			
Tongue task latencies (in s)	16.96	3.57	5.50–18.75
Dinky toys task scale	3.80	1.36	1.00–5.00
Wrapped-gift task scale	4.35	1.09	2.00–5.00
Wrapped-gift task latencies (in s)	50.20	17.13	24.00–60.00
Bow task scale	3.65	.49	3.00–4.00
Bow task latencies (in s)	145.15	55.65	29.00–180.00
Temperament parent report (CBQ)			
Effortful control factor			
Attention focusing scale	4.80	.68	3.67–5.89
Inhibitory control scale	4.70	.59	3.69–5.92
Low sensitivity pleasure scale	5.73	.51	4.31–6.40
Perceptual sensitivity scale	5.25	.81	4.31–6.40
Additional scales of interest			
Anger/frustration scale	4.75	.73	3.33–6.00
Approach/anticipation scale	5.37	.48	4.31–6.00
Peabody picture-vocabulary test	115.30	9.93	90.00–134.00

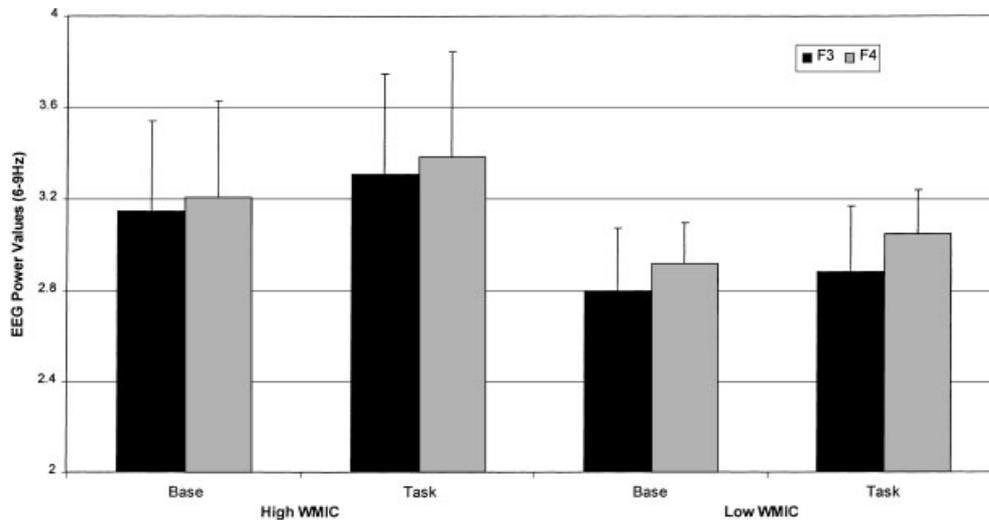
power at left (C3;  $M = 3.1970$ ,  $SD = .364$ ) than at right (C4;  $M = 3.1164$ ,  $SD = .386$ ).

**Anterior Temporal (T3, T4).** There was a group main effect,  $F(1, 18) = 5.547$ ,  $p = .030$ , with the high-performance group showing greater overall EEG power values than the low-performance group (see Figure 3).

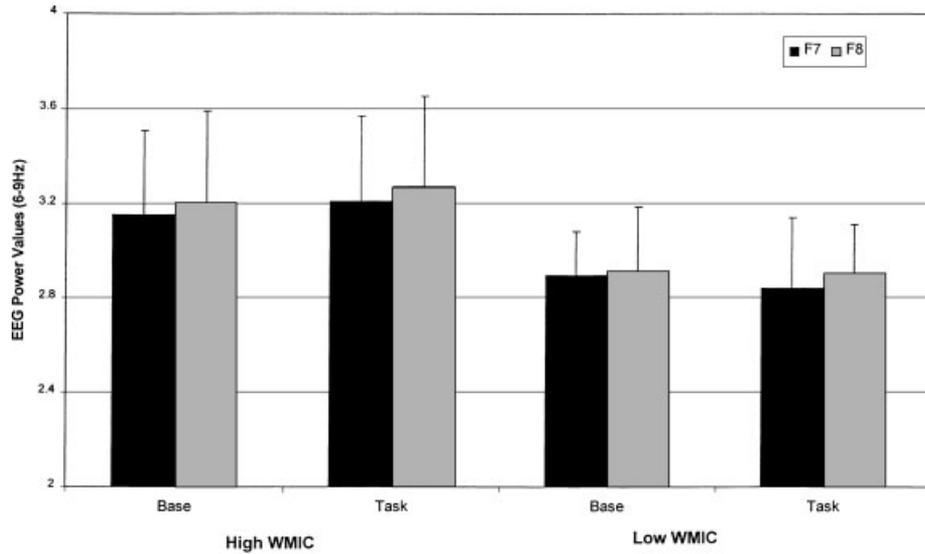
**Posterior Temporal (T5, T6).** There was a main effect for hemisphere,  $F(1, 18) = 9.671$ ,  $p = .006$ , with greater EEG power at left (T5;  $M = 3.392$ ,  $SD = .404$ ) than at right (T6;  $M = 3.275$ ,  $SD = .350$ ).

## HP and WMIC

This analysis tested for HP differences between baseline and task differences and for WMIC performance group differences in HP values. A repeated measures MANOVA was done on the HP values. The within-subjects factor was condition (i.e., baseline and task), and the between-subjects factor was cognitive task performance group (i.e., low and high). There was a main effect for condition,  $F(1, 15) = 7.29$ ,  $p = .016$  (baseline  $M = 594.25$ ,  $SD = 52.31$ ; task  $M = 578.85$ ,  $SD = 48.67$ ). HP decreased (hence HR increased) from baseline to task. There was



**FIGURE 1** EEG power values (in 6–9 Hz) from medial frontal (F3, F4) scalp locations for the two WMIC groups during baseline and task.



**FIGURE 2** EEG power values (ln 6–9 Hz) from lateral frontal (F7, F8) scalp locations for the two WMIC groups during baseline and task.

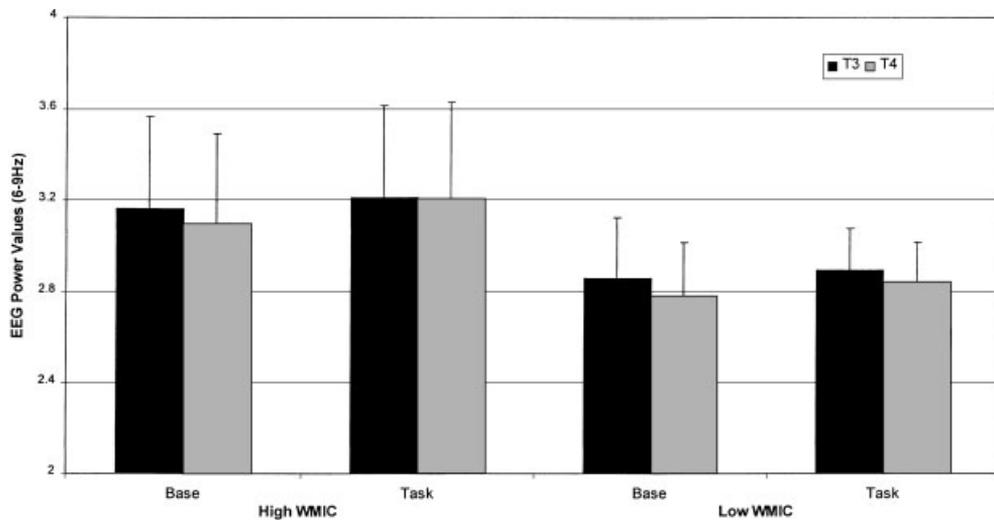
no main effect for group and no Group  $\times$  Condition interaction,  $F_s < 0.87$ ,  $p_s > .05$ .

### Temperament

**Laboratory Measures.** An association was found between the wrapped-gift score and the WMIC performance,  $r = -.38$ ,  $p < .05$ . No other correlations were significant,  $r_s < .22$ ,  $p_s > .05$ .

**Parent Report.** Pearson correlations were calculated between WMIC scores and all CBQ scales, those hypothesized to be related (one-tailed) and those without

hypotheses (two-tailed). With regard to the subscales of the effortful control factor, hypothesized associations were found between WMIC performance and the attentional focusing scale,  $r = .377$ ,  $p = .05$ , and the inhibitory control scale,  $r = .365$ ,  $p = .057$ , but not for the low sensitivity pleasure or the perceptual sensitivity scales,  $r_s < .01$ ,  $p_s > .05$ . As was hypothesized, a negative relation was found between WMIC performance and the anger/frustration scale,  $r = -.381$ ,  $p < .05$ . An additional, unexpected, relation was found between WMIC performance and the approach/anticipation scale,  $r = -.555$ ,  $p = .01$ ; two-tailed.



**FIGURE 3** EEG power values (ln 6–9 Hz) from anterior temporal (T3, T4) scalp locations for the two WMIC groups during baseline and task.

**Table 3. Pearson Correlations Calculated Between CBQ Scales of Interest, the WMIC Tasks, and Two Effortful Control Tasks**

CBQ Scales of Interest	WMIC Tasks	Effortful Control Tasks	
		Tongue	Wrapped Gift
Effortful control scales			
Attention focusing	.377	—	—
Inhibitory control	.365	-.346	-.404
Low sensitivity pleasure	—	—	—
Perceptual sensitivity	—	.409	—
Additional scales of interest			
Anger/frustration	-.381	.464	.550
Approach/anticipation	-.555	—	.373

Note. All  $p$ 's  $\leq .07$  for the correlations listed.

There were several associations found between CBQ temperament scales and two effortful control laboratory measures (see Table 3). Specifically, parental ratings of perceptual sensitivity were positively related to performance on the tongue task,  $r = .409$ ,  $p < .05$ . Parental ratings of inhibitory control were negatively associated with performance on the tongue task,  $r = -.35$ ,  $p < .05$ , and the wrapped-gift task,  $r = -.40$ ,  $p < .05$ . Further, positive relations were found between the CBQ anger/frustration scale and the tongue task,  $r = .464$ ,  $p < .05$ , as well as with the wrapped-gift task,  $r = .550$ ,  $p < .01$ . The approach/anticipation dimension of temperament was positively related to performance on the wrapped-gift task,  $r = .373$ ,  $p = .05$ ; two-tailed.

**Language Measure.** To test for WMIC group differences on the language measure, an ANOVA was conducted on the PPVT-III standardized scores, with WMIC group as the between-subjects factor (i.e., high and low). Children in the high WMIC group had higher language scores than the children in the low WMIC group,  $F(1, 18) = 12.27$ ,  $p = .003$  (high  $M = 120.33$ ,  $SD = 6.53$ ; low  $M = 107.75$ ,  $SD = 9.61$ ).

### Collective Contributions to WMIC

In the previous analyses, several variables were associated with the WMIC tasks, specifically EEG power from the medial frontal region (F3/F4), performance on the language assessment, and four CBQ temperament scales—attention focusing, inhibitory control, anger/frustration, and approach/anticipation. To determine the collective value of these variables in predicting WMIC group, a stepwise discriminant function analysis was performed using seven variables as predictors of member-

**Table 4. Results of the Stepwise Discriminant Function Analysis Predicting WMIC Performance Group From Electrophysiology (EEG), Temperament (CBQ), and Language (PPVT-III)**

Variables in the Analysis	Wilks's $\lambda$	Exact $F$	$df1$	$df2$	Significance
PPVT-III	.594	12.28	1	18	.003
PPVT-III	.392	13.17	2	17	.000
EEG (F3)					
PPVT-III	.260	15.19	3	16	.000
EEG (F3)					
CBQ (approach)					

ship in the two WMIC groups (i.e., high and low). Predictors were left medial frontal task-related EEG (F3), right medial frontal task-related EEG (F4), the PPVT-III standardized score, and four CBQ scale scores—attention focusing, inhibitory control, anger/frustration, and approach/anticipation. The results of this analysis yielded three predictors of WMIC group: The PPVT-III language measure, the left medial frontal EEG power (F3), and the approach/anticipation dimension of temperament,  $\chi^2(3) = 22.237$ ,  $p = .001$  (see Table 4). Together, these three variables were able to correctly classify 90% of the children to high and low WMIC groups (see Table 5).

### DISCUSSION

We examined the cognitive skills of WMIC in early childhood in relation to (a) physiological functioning, (b) several temperament dimensions, including the scales that comprise Rothbart's effortful control factor, and (c) language receptivity. Associations were found between WMIC performance and brain electrical activity, four temperament scales, and the children's receptive vocabulary scores. However, before interpretation and discussion of this research can be presented, it is important to highlight a limitation of this study: the small and potentially biased sample.

Recall that as a longitudinal study our recruitment was restricted to those families remaining in the area after

**Table 5. Classification Results for Discriminant Function Analysis**

Original Count	Predicted Group Membership		
	Low WMIC	High WMIC	Total
Low WMIC	7 (87.5%)	1 (12.5%)	8
High WMIC	1 (8.3%)	11 (91.7%)	12

Note. Correct classification = 90.0%.

4 years (27 of 50 families), and further, to those children who were willing to participate in all aspects of the laboratory visit, contributing to our small sample size ( $n = 20$ ). Specifically, of those families remaining in the local area, two families declined participation in the study: One parent replied that the family was too busy, and one parent reported that her child was too shy to participate. Because temperament was a variable of interest in the current study, the nonparticipation of the shy child could have potentially biased our sample. However, based on the analyses performed on the CBQ temperament measures and the WMIC tasks, there were no associations found involving the shyness scale,  $r_s < .14$ ,  $p_s > .05$ . Therefore, there is no reason to believe this particular child's contribution—or lack thereof—would be confounding to our results.

Another potential source of bias included the elimination of 4 participants from the analyses due to incomplete data that may have resulted from the child's temperament. Recall that 2 children refused to wear the EEG cap, 1 child wore the cap but refused the application of the EEG preparation gels, and 1 child refused to finish the tasks. Thus, an important question to answer is do these self-selected children differ systematically on any variable of interest from those children who participated in and completed all procedures? These children do, in fact, differ on one variable, the CBQ attention focusing scale. Unexpectedly, those children who refused some procedures had lower parental ratings of attention focusing (i.e., the tendency to maintain attentional focus upon task-related events and activities) than those children who completed all procedures. This finding should be considered when interpreting the results. However, although the children who were self-eliminated from the study were lower than the entire group on the attention focusing scale, when the self-included children were divided into low and high groups based on a median split categorization, the self-eliminated children were no different than the self-included children classified as low on attention focusing. The expectation might have been that these children would have been rated differently by their parents on shyness, but this was not the case. Thus, the lower attention focusing ratings were both intriguing and unexpected.

With this limitation in mind, the first goal of this study was to extend infant EEG research on WMIC to the early childhood years. Previous EEG work investigating these constructs in infancy showed an increase in 6- to 9-Hz EEG power from baseline to task for several frontal and some posterior cortical regions (Bell, 2001, 2002). One of the research questions guiding this study was whether task-related change at 6 to 9 Hz would be evident for preschool children as well. Previous longitudinal work had demonstrated that 6 to 9 Hz continues to be the

dominant frequency band for 4-year-olds during a baseline context (Marshall et al., 2002). The data from this study suggest an increasing specialization of cortical activity for these WMIC skills during the early years. More specifically, the increase in EEG power from baseline to task was evident for the medial frontal region only. This specificity is comparable to the fMRI work done by Casey et al. (1995; Casey et al., 1997; Durston et al., 2002), with older children correlating frontal cortical activity with executive skills such as working memory and inhibitory control. These findings may yield insight into qualitative changes in cortical functioning from the infant to the early-childhood time periods, adjustments indicative of developmental changes in brain specialization.

A second research question of interest, based on previous EEG work with infants using an age-appropriate WMIC task (Bell, 2001), concerned individual differences in baseline- and task-related EEG. Would high performers exhibit greater EEG power values during the task than children who are less successful on the WMIC tasks? Rather than finding an increase in EEG power from baseline to task, there was a trend ( $p = .064$ ) for the high WMIC performers to have greater EEG power values overall (i.e., baseline and task) than the low performers. That is, there was no Group  $\times$  Condition interaction. Although this does not replicate infant work, the EEG power values of the high performers tend to be higher than those of the lower performers, indicating greater maturation of the EEG (Bell, 1998). Perhaps a larger sample size would allow a more definitive evaluation of individual differences in WMIC and associated brain electrical activity.

In addition to examining the EEG correlates of WMIC in early childhood, this study also investigated the relation between baseline and task measures of HP. A decrease in HP (corresponding to an increase in HR) from baseline to task was found. This finding, in addition to the increase in EEG power from baseline to task, indicates that these two WMIC tasks (i.e., the day–night Stroop-like task and the yes–no task) are cognitive stressors for  $4\frac{1}{2}$ -year-old children and provides further evidence that effortful, volitional abilities are maturing in early childhood. Unlike the EEG findings from this study, however, there was no indication of individual differences in HP functioning. In other words, the high WMIC performance group did not exhibit a decrease in HP to the exclusion to the low WMIC group. This was surprising, given the developmental psychophysiology literature suggesting that individual differences in cardiac functioning are associated with varying levels of information processing (e.g., Ruff & Rothbart, 1996). However, studies in the developmental literature focus on attentional processes, and this study focused on working memory and inhibitory control processes. Perhaps individual differences in

cardiac functioning are not as prominent with higher order cognitive processing during childhood.

Based on recent suggestions in the developmental literature that cognition and temperament share developmental components (e.g., Fox, 1994; Ruff & Rothbart, 1996), we explored the similarity of the cognitive construct of inhibitory control (using the WMIC tasks) and the temperament aspect of effortful control (using laboratory tasks). Because each of these constructs involves inhibiting a dominant response to perform a subdominant response, and because each is associated with some aspect of frontal functioning, we wanted to know if performance on WMIC tasks would be related to performance on laboratory effortful control tasks. We found only one association: WMIC performance and the wrapped-gift task were negatively related. That is, those children who did very well on the WMIC tasks did not perform as well on the wrapped-gift task. This finding is isolated and contrary to our hypothesis. We did not utilize the entire battery of laboratory effortful control tasks presented by Kochanska et al. (2000). Perhaps if we had used the complete battery of tasks, we would have found additional associations. The tasks that we did use were focused on the ability to delay, only a part of the effortful control construct. In addition, Kochanska et al. (2000) used these effortful control tasks with younger children, approximately 22 to 33 months of age. It is conceivable that this group of tasks does not tap the same effortful control construct with 4½-year-olds.

Relations were found between WMIC scores and parent report of temperament using the CBQ. Importantly, positive associations were found between WMIC performance and two of the four scales that comprise the effortful control factor, attention focusing and inhibitory control, but no associations were found for the other two scales (i.e., low sensitivity pleasure and perceptual sensitivity). It is understandable that these two scales of the effortful control factor would be related to performance on the WMIC task, as they seem to draw on the more cognitive component of the factor—especially when compared to the low sensitivity pleasure and perceptual sensitivity scales. Additionally, a negative relation was found for the anger scale, as expected. This is consistent with the findings and theorizing of previous researchers (e.g., Gerardi-Caulton, 2000) and suggests that children who perform better on the WMIC tasks also have a greater ability to regulate their anger and frustration.

Further, the laboratory measures of effortful control and parent ratings of temperament were related, but not in the predicted direction. As seen in Table 3, the effortful control tasks yielded negative relations with the parental ratings of inhibitory control and suggests that children with higher parental ratings of inhibitory control perform poorer on these effortful control tasks than children with

low ratings of inhibitory control. When noting the general patterns of associations displayed in Table 3, it is interesting that the direction of association for the temperament scales with the WMIC tasks and the effortful control tasks are opposite. For example, parent-rated inhibitory control is positively related to WMIC performance, but negatively related to both effortful control tasks. With regard to the anger and approach/anticipation scales, they are negatively related to WMIC performance, but positively related to the effortful control tasks. These findings suggest that the WMIC and the effortful control tasks require different skills and suggest that the appropriateness of using these effortful control laboratory tasks with 4½-year-olds is worthy of further investigation.

Interestingly, WMIC performance was negatively correlated to parental ratings of approach/anticipation, an unexpected but rather robust relation. Considering the CBQ items that comprise the approach/anticipation scale may provide some insight into this negative association (see Table 6). In fact, some of the items are directly related to the behaviors required during the laboratory visit (e.g., shows great excitement about opening a present and gets so excited about things she or he has trouble sitting still). Although these findings are contrary to some work with temperament and cognition that reports outgoing and sociable children scoring higher on mental tasks, it is consistent with the findings of Davis et al. (2002), who reported an unexpected, strong negative correlation between the surgency/extraversion factor of the CBQ and performance on inhibitory control tasks used by Casey and colleagues (e.g., Casey et al., 1997). The surgency/extraversion factor includes the approach/anticipation scale.

This may be consistent with Bloom's theory of language acquisition (Bloom, 1993, 1998) as well. Bloom suggests that neutral, rather than positive or negative affect, is advantageous for cognitive development, specifically language development, because it allows for

**Table 6. Examples of CBQ Items Comprising the Approach/Anticipation Scale**

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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
When s/he wants to do something, s/he talks about little else
Has strong desire for certain kinds of foods
Looks forward strongly to the visit of loved relatives
Becomes very excited while planning for trips
Becomes very excited before an outing (e.g., picnic, party)
Gets very enthusiastic about the things s/he does
Shows great excitement about opening a present
Becomes very excited about upcoming television programs
Shows great excitement about upcoming desserts like ice cream

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more cognitive capacity to process other information. The negative relation between WMIC performance and the approach/anticipation dimension of temperament suggests that children who have lower parental ratings of approach/anticipation tend to perform higher on measures of WMIC. Perhaps these high WMIC children either do not get as enthusiastic about upcoming events or treats or, more likely, they do get as enthusiastic but have acquired the self-regulation skills necessary to be excited but also focus their attention to the task at hand.

Furthermore, the children with the highest WMIC scores also had the highest language achievement. This finding complements the work of Adams and Gathercole (1995) by linking the development of language with the development of WMIC skills. A high score on the PPVT-III suggests strong comprehension and understanding of the spoken word—a skill that is advantageous for performance on a task in which following orally given instructions is crucial.

The last research question explored the collective contributions of physiology, temperament, and language in the prediction of WMIC performance group. Considered separately, individual variables showed associations with the WMIC score or WMIC group membership. Considered together, these variables were able to accurately predict 90% of WMIC group memberships, with the significant predictors being PPVT-III score, left frontal EEG (F3) power, and the CBQ approach/anticipation score. Interestingly, variables representing each domain of study (i.e., physiology, language, and temperament) were identified as significant predictors of WMIC performance group. The predictive variables yielded from this analysis are not surprising, as these variables boasted the strongest relations with WMIC performance.

The unique contribution from the left medial frontal region (F3), independent of the right frontal region (F4), is intriguing, but unpredicted. Infant EEG recorded during working memory and sustained attention tasks exhibits task-related EEG changes at both anterior and posterior scalp locations (Bell, 2001, 2002; Orekhova et al., 2001). The unique contribution of left frontal EEG in this study may be indicative of brain reorganization towards increasing specialization from infancy to early childhood. Likewise, the contribution of left frontal EEG may be related to temperament associations during cognitive processing or even during the experimenter interaction. Fox (1994) highlighted the links between left frontal EEG levels and the temperament behaviors of approach, positive affect, and sociability. Perhaps the contribution of left frontal EEG to WMIC performance is a temperament-related factor that might indirectly influence performance on interactive cognitive measures. It may be that those children with greater left frontal EEG (i.e., more sociable and more willing to approach the novel

experimenter and situation) were able to achieve higher levels of performance on the WMIC tasks than those children without greater left frontal EEG power, although there were no WMIC performance associations with parent-rated shyness or sociability. We plan to explore these interesting findings in future longitudinal work.

Thus, as this exploratory study involves the consideration of multiple perspectives in the study of cognitive development, it sets the stage and provides the impetus to further explore the associations between temperament and cognition.

## NOTES

A portion of these data was presented at the biennial meeting of the International Conference on Infant Studies in Toronto, April 2002. The authors would like to acknowledge Susan Daugherty for the “yes–no” concept that was the basis for the yes–no task used in this study.

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