REGIONAL DIFFERENCES IN TASK-RELATED BRAIN ELECTRICAL ACTIVITY AND SOURCES OF VARIABILITY IN WORKING MEMORY FUNCTION IN EARLY CHILDHOOD

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(ABSTRACT)

The focus of this project falls largely within the realm of investigating the development of brain-cognition relations from a developmental cognitive neuroscience perspective. There were two main goals of this study. First, this study focused on the regional differences in baseline-to-working memory task brain electrical activity and specifically investigated the hypothesis that there would be an increasing specificity of task EEG power between 3½ and 4½ years of age. The second goal of this study was to investigate the sources of variability in working memory function and to specifically examine the contributions of task-related EEG, the regulatory dimensions of temperament, and linguistic ability to the prediction of working memory performance. This second study objective included an investigation of the relation between working memory and each of these variables (1) separately, (2) in conjunction with age, and (3) collectively to examine any multivariate contributions to the explanation of variance in working memory function in early childhood.

The results of this study provided some support to the increasing specificity of baseline-to-task EEG power hypothesis. Specifically, an increase in brain electrical activity was found for four scalp regions at age 4 and only two regions at age 4½. These findings coupled with previous work indicating an increase in task brain electrical activity for only one region at age 4½ suggest that cortical specialization is occurring during the early childhood years. With regard to the investigation of sources of variability working memory function, age, brain electrical activity, temperament, and linguistic functioning were all found to be meaningful variables in the explanation of variance in working memory. However, linguistic functioning – and specifically language receptivity – was found to be the strongest and most meaningful associate of working memory function. Additional findings of interest included the differential associations demonstrated between working memory and temperament for each age group and also an increase in the strength of the relation between working memory and language across the three ages.

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Executive function is a prominent construct in the traditional cognitive psychology literature. It is comprised of higher order cognitive skills such as working memory, inhibitory control, planning, attentional flexibility, representation flexibility, and temporal monitoring (e.g., Baddeley, 1996; Norman & Shallice, 1986) and is typically associated with the functioning of the prefrontal cortex (e.g., Petrides, 2000). Within the past few years, this multifaceted construct has become a popular topic in developmental psychology as well (e.g., Welsh, Pennington, & Grossier, 1991; Zelazo, Muller, Frye, & Marcovitch, 2003). The extension of this construct to the developmental literature can be attributed to the creation of developmentally appropriate forms of adult executive function tasks and the evidence of rudimentary forms of executive function in very young children – specifically working memory function (Diamond, Prevor, Callender, & Druin, 1997; Diamond & Taylor, 1996; Gerstadt, Hong, & Diamond, 1994; Wolfe & Bell, 2004a).

A traditional model of working memory function includes an integrative system of components including a visuospatial sketchpad for briefly holding visual images for reflection or manipulation; a phonological (or articulatory) loop for briefly holding inner speech for verbal comprehension and acoustic rehearsal; and a central executive component which has been less well-defined but is typically implicated in the allocation of attentional resources and the governing of responses (Baddeley, 1990; Baddeley & Hitch, 1974). Another increasingly popular model, or organizational framework, of working memory function includes these domain-specific components as described by Baddeley (e.g., phonological loop, visuospatial sketchpad) but also includes a domain-free, limited capacity controlled attention component and implicates the functioning of the dorsolateral prefrontal cortex (DL-PFC) in the mediation of working memory processes (Engle, Kane, & Tuholski, 1999; Kane & Engle, 2002).

The domain-free, limited capacity controlled attention component can be conceived as "executive attention" as it allows for the allocation of attentional resources and for the cognitive inhibition to external events (environmental distracters) and internal demands (irrelevant information from long term memory or from the task at hand). It is this executive attention component that delineates working memory and short term memory, and it is this component that is closely associated with the functioning of the DL-PFC. Although the importance of other brain systems is recognized in the working memory process (i.e., the anterior attention network and specifically the anterior cingulated cortex), Engle's framework assigns the DL-PFC a special role for executive attention such that it "actively maintains access to stimulus representations and goals in interference-rich contexts" (Kane & Engle, 2002, p. 637).

Another unique feature of Engle's model is the emphasis placed on individual differences in working memory capacity and function. Specifically, individual differences in the functioning of the aforementioned components – the visuospatial sketchpad, phonological loop, capacity for controlled attention, and functioning of the DL-PFC – are associated with individual differences in working memory. It is this conception of working memory that provides the conceptual and theoretical framework for the cognitive skills under study in the current project.

Engle's model is applicable to working memory function in young children, and there is substantial research to support its utility. Indeed, research indicates that young children from the ages of 3½ to 7 years can perform cognitive tasks that require focused attention as well as the integration of working memory and inhibitory control (e.g., Diamond et al., 1997). For example, the tapping task (Diamond & Taylor, 1996), the Stroop-like day-night task (Gerstadt, Hong, &

Diamond, 1994), the yes-no task (Wolfe & Bell, 2004), and the dimensional change card sort task (DCCS; Zelazo, Muller, Frye, & Marcovitch, 2003) have been successfully used in the developmental literature. Each of these tasks requires the child to remember and employ a set of rules and to inhibit a more dominant or prepotent response. Prefrontal functioning, and specifically the DL-PFC, has been implicated in the performance of these working memory tasks (Diamond et al., 1997; Luria, 1961; Wolfe & Bell, 2004a).

Further, Diamond and colleagues (Diamond et al., 1997; Diamond & Taylor, 1996; Gerstadt, Hong, & Diamond, 1994) have demonstrated substantial increases in working memory function during the early childhood years – a time when many changes are occurring in the brain including an increase in size and density largely due to myelination and the proliferation of dendritic branches and synaptic connections. The working memory tasks typically employed by Diamond's research program are those that require the participant to hold some information in memory and to also inhibit a prepotent response. For example, tasks that have been used with young children are the day-night Stroop-like task and the tapping task (Diamond & Taylor, 1996; Diamond et al., 1997; Gerstadt et al., 1994). In both of these tasks, children are required to remember two rules and to inhibit a dominant response. In the day-night 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. In the tapping task, the children are instructed to tap once when the experimenter taps twice and to tap twice when the experimenter taps once. Therefore, in both tasks, the children are required to remember two rules (i.e., the instructed responses for each stimulus) and to also inhibit a dominant response (i.e., the tendency to label the picture correctly or tap in synchronization with the experimenter).

Employing the day-night task and the tapping task with children between the ages of 3 and 7 years of age, Diamond and Taylor (1996) reported linear increases in performance – in both accuracy and speed – with age. These authors highlighted the dramatic increases in performance occurring before age 6 and also the high variability in performance between the ages of 3½ and 5 years. Further, these authors noted that several 3½ -year-olds had difficulty with the tasks and either would not play or did not pass the pretests. Incidentally, none of the 3-year-olds tested provided usable data; the task appeared too difficult for them. Wolfe and Bell (2004a, 2004b) employed the tapping and the day-night tasks with 4½-year-old children and yielded comparable results with Diamond on both tasks. In short, these tasks are too difficult for 3-year-olds, by 3½ years of age some children are experiencing success, and by 4½ years of age most children are performing well above chance levels.

Like the tapping and day-night tasks, age-related changes in performance on the Dimensional Change Card Sort (DCCS; Frye, Zelazo, & Palfai, 1995; Zelazo, Frye, & Rapus, 1996) suggest that executive function skills develop rapidly during the preschool years. The research program of Zelazo and colleagues (e.g., Zelazo et al., 2003) equates performance on the DCCS with executive function abilities – specifically including the working memory, executive attention, and inhibitory control components – in young children. In the DCCS, children are shown two target cards (e.g., a blue flower and a red car) that vary along two dimensions (e.g., color and shape), and they are instructed to sort a series of test cards (e.g., red flowers and blue cars), first according to one dimension and then according to the other. Results of the administration of the DCCS are highly consistent. Specifically, 3- to 4-year-olds typically perseverate by sorting cards by the first dimension regardless of which dimension is presented first. Interestingly, the preschoolers make this mistake even when they are told the new rules on every trial, even when they have sorted the cards by the new dimension on other occasions, and even when they have correctly answered questions about the postswitch rules (Zelazo et al., 2003). In contrast, by 5 years of age, children typically perform well on the DCCS.

Several other research programs have supported the dramatic increases in cognitive control during the preschool years. Luria (1961) reported that when asked to press a balloon two times when a light appears, that children ages 3-4 years are unable to inhibit the motor program once it has begun and press the balloon many times in succession, whereas 5-year-old children have no difficulty with this procedure. Livesey and colleagues (Bell & Livesey, 1985; Livesey & Morgan, 1991) noted that children 3-4 years of age tend to fail go/no-go tasks because they cannot inhibit responding even when they understand the task and can verbalize the instructions. Children 5-6 years of age, however, easily succeed on these go/no-go tasks. Flavell, Green, & Flavell (1986) investigated a similar cognitive construct – representational flexibility – in young children by presenting children with a misleading object (e.g., a sponge painted to look like a rock) and asked about its appearance and true nature (i.e., What does this look like? What is this really?). Three-year-olds were much more likely than 5-year-olds to give the same answer to both questions.

The timeline of these developmental advances – both behavioral and physiological – are in accordance with one of the major theories in developmental psychology – Piaget’s theory of cognitive development. Piaget’s theory characterizes young children (i.e., 2-4-year-olds) as “preoperational” and describes their thinking as egocentristic and inflexible. A child in Piaget’s preoperational stage, for example, uses him/herself as the center of judgment, is unable to take the perspective of someone else, and tends to focus on only one characteristic of an object or situation. These behaviors can be seen in the young children’s failure on perspective taking tasks in which they respond as if other people share their own perspective and on conservation tasks in which, for example, they focus only on the height of the liquid and disregard the width. It is as if children 3 or 4 years of age have difficulty keeping two things in mind at one time or tend to focus on only one aspect of a problem. Older children are much more likely to consider two or more aspects of a problem or to exhibit representational flexibility. Children 5 or 6 years of age easily succeed at these perspective taking and conservation tasks presumably because they have the ability to manage several pieces of information at a time and to consider problems from different perspectives.

To what can we attribute these dramatic increases in working memory function during these preschool years? The previous review focused on the variability in performance that is associated with age, but are these increases simply a function of age? Other factors have been associated with individual differences in working memory function. For example, the development of certain brain structures, such as the DL-PFC and the anterior cingulate cortex, the temperament characteristics of the child, and the linguistic abilities of the child have been theoretically and empirically associated with the development of working memory and executive attention. The current study investigated the development of working memory function in children 3½, 4, and 4½ years of age and examined the sources of variability in this construct. The factors found to be associated with the development of working memory function and hence of interest in this study were age, brain electrical activity, temperament, and linguistic ability.

Electrophysiological Correlates of Working Memory Function in Early Childhood

The association between the development of certain cognitive skills and changes within the brain has been of interest to theorists and researchers for centuries. It is considerably valuable to investigate these relations from a developmental perspective focusing on both infants and young children, because there is much anatomical and functional change taking place in the brain and many corresponding advances being made in the cognitive domain during these early years. Recent technological advances with respect to neuroimaging techniques (e.g., EEG, ERP, *f*MRI) have facilitated the study of brain-cognition relations and have specifically opened up an avenue of research with younger populations that has previously not been accessible. EEG is an especially valuable measure of brain activity in infants and young children as it has good time resolution, is relatively non-invasive, and is relatively inexpensive.

Indeed, the constructs of working memory and inhibitory control, have been the focus of much behavioral (Diamond et al., 1997; Diamond & Taylor, 1996; Gerstadt et al., 1994; Welsh et al., 1991), electrophysiological (Bell, 2001, 2002; Bell & Fox, 1992, 1997), and neuroscience research (Casey et al., 1995, 1997; Diamond, 1990a, 1990b, 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 working memory tasks are developing during infancy and the early childhood years.

The rudiments of working memory and executive attention – such as recall of declarative memories (Nelson, 1995), deferred imitation (Carver, Bauer, & Nelson, 2000; Hayne, Boniface, & Barr, 2000), voluntary or sustained attention (Richards & Casey, 1991; Rothbart & Bates, 1998; Ruff & Rothbart, 1996), and inhibitory processes (Bell, 2001; Diamond, 2001) – are evident as early as infancy. The second half of the first year of life is a particularly important time for the appearance of these types of cognitive skills – a time when rapid changes are taking place in brain organization and for the frontal cortex in particular (Bell, 2001; Chugani, 1994). For example, it has been demonstrated that the maturation of the frontal cortical region in infants – marked by increasing baseline frontal electroencephlagraphic (EEG) power values – is associated with increased performance on a classic task of spatial working memory – Piaget's A-not-B task (Bell & Fox, 1992; 1997). Higher occipital EEG power values during baseline also have been 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, 2004). 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 working memory skills and showed no change in EEG power values from baseline to task (Bell, 2001). Infants have shown a similar pattern of increase in EEG power values from baseline to task during sustained attention (Orekhova, Stroganova, & Posikera, 1999; Stoganova, Orekhova, & Posikera, 1998, 1999) and cortical inhibition tasks (Orekhova, Stroganova, & Posikera, 2001) as well.

Although baseline-to-task increases in EEG power values for frontal and posterior scalp regions have been associated with the development of working memory in infants, only one study to date (Wolfe & Bell, 2004a, 2004b) has examined this specific relation in the early childhood years (although see Debeus, 2000, for research with young children using EEG coherence measures and a working memory task) – a time when, as previously noted, many advances are being made in working memory and executive attention (Diamond & Taylor, 1996; Diamond et al., 1997; Gerstadt et al., 1994; Luciana & Nelson, 1998; Welsh et al., 1991). The substantial changes in these higher order cognitive constructs may reflect important changes within the prefrontal cortex during this period of life (Diamond & Taylor, 1996).

Indeed, Wolfe and Bell (2004a) examined working memory skills in early childhood in relation to electrophysiological functioning, specifically the electrical activity recorded from the scalp (i.e., EEG). The children's working memory abilities were assessed with the Stroop-like day-night task and the yes-no task (a task similar in procedure to the day-night task – children are required to remember two rules and to inhibit a dominant response tendency that is to say "no" when the experimenter nods her head yes and to say "yes" when the experimenter shakes her head no). One of the research questions that guided this particular study was whether task-related power change at 6-9 Hz would be evident for preschool children as it had been for infants. Previous longitudinal work demonstrated that 6-9 Hz continues to be the dominant frequency band for preschool children during a baseline context and further purported that 6-10 Hz would be appropriate for older preschoolers (Marshall, Bar-Haim, & Fox, 2002). The results of Wolfe and Bell (2004a, 2004b) suggested an increasing specialization of cortical activity for the working memory 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 pattern of activation was notably different than that found in the research with infants in which frontal and posterior scalp locations were indicated.

This increasing specificity is comparable to the *f*MRI work done by Casey and colleagues (1995, 1997; Durston et al., 2002) with older children correlating frontal cortical activity with executive skills such as working memory and inhibitory control. Specifically, *f*MRI data were 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, 1997;

Durston et al, 2002). This work indicated cortical activation along the frontal midline – again a notably different activation pattern than was found in the infant EEG research – but a similar activation pattern found in the preschool EEG research where only the medial frontal region showed an increase in power. 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.

If there is an increasing specificity of electrical activity between infancy and age 4½, the question remains, at what point between infancy and early childhood does this increase in specificity occur? The first goal of this study is to extend the previous research with 4½-year-old children to include 3½- and 4-year-old children to assess age-related changes in working memory function and the associated physiological functioning and specifically to answer the following research question: Is there an increasing specificity of baseline-to-task EEG power with age such that multiple (e.g., frontal and posterior) brain regions increase in power from baseline-to-task for the 3½-year-olds but only one region (i.e., medial frontal) shows increases in power for the 4½-year-olds?

An additional electrophysiological research interest focused on individual differences and involved the association between brain electrical activity and working memory performance. Wolfe and Bell (2004a, 2004b) found left medial frontal (F3) EEG power to be a meaningful associate and predictor of working memory performance at age 4½ years of age. The current study considered the value of the left medial frontal EEG power, once again, in the explanation of variance in working memory performance for these three age groups and asked the following research questions: Does left medial frontal EEG power explain a significant portion of variance in working memory performance? If so, does this variable explain unique variance above and beyond the age variable? Finally, is there an interaction effect such that this relation holds for one age but not another?

Additional Sources of Variability in Working Memory Function

In addition to the aforementioned age and the electrophysiological correlates of working memory function, there are two other constructs that have been associated with the development of this cognitive skill. These constructs are temperament, specifically the regulatory and surgent dimensions of temperament, and linguistic ability.

Temperament. In addition to the development in working memory skills and cognitive control during preschool years, another aspect of self-regulation that improves dramatically is the control of emotions and related behaviors (e.g., Kochanska, Murray, & Harlan, 2000; Kopp, 1982). With regard to the development of emotional inhibitory control for example, Mischel and Mischel (1983) examined the delay of gratification abilities in young children. They found that children of 4 years are unable to inhibit going for the immediate small reward instead of waiting for a larger one if they could wait for a lengthier period of time, but older children can easily wait for the larger reward. Similarly, Russell, Mauthner, Sharpe, and Tidswell (1991) reported that on a windows task in which children are rewarded for pointing to a box which is visibly empty, and are not rewarded for pointing to a box in which they can see candy, 3-year-olds fail to inhibit the tendency to point to the baited box.

The development of these emotion related self-regulatory abilities is likely related to the development of the aforementioned cognitive inhibitory control abilities. Piaget (1952) suggested that there is no such thing as a purely cognitive or purely affective state. Recent research and theorizing on brain-behavior relations suggests that cognition and emotion are not orthogonal but are dynamically linked to process information and plan response (Bell & Wolfe, 2004; Bush, Luu, & Posner, 2000; Cacioppo & Bernston, 1999). There is a growing interest in this cognition-emotion relation (e.g., Blair, 2002; Bush et al., 2000; Fox, 1994; Rothbart & Derryberry, 1981; Rothbart, Derryberry, & Posner, 1994; Ruff & Rothbart, 1996) and initial research attempts to support this assertion focusing on temperament as emotion have been successful (Andersson & Sommerfelt, 1999; Bauer, Burch, & Kleinknecht, 2002; Halpern, Garcia Coll, Meyer, & Bendersky, 2001; Kubicek, Emde, & Schmitz, 2001; Martin & Holbrook, 1986; 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 and attentional reactivity and the emergence of self-regulation or inhibitory control of that reactivity beginning late in the first year of life. The emergence of these early regulatory processes may have implications for cognitive development as well (Bell & Wolfe, 2004; Bush, Luu, & Posner, 2000; Fox, 1994; Ruff & Rothbart, 1996; Wolfe & Bell, 2004a, 2004b). Late in the first year infants also begin to exhibit inhibitory control on working memory tasks (Diamond, 1990a; Diamond et al., 1997). Thus, even during infancy the development of both emotion and higher order cognition may require the initial integration of some degree of controlled, effortful processing and response (Bell & Wolfe, 2004b). Blair (2002) has suggested that cognition and emotion likely are integrated by school age.

One of Rothbart’s childhood temperament factors of interest to the current study is Effortful Control. This factor is one of three broad factors reliably ascertained by a clustering of several item scales of the Children’s Behavior Questionnaire (CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001). The Effortful Control factor is 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, Murray, & Harlan, 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, Fabes, Bernzweig, Karbon, Poulin, & Hanish, 1993; Mischel, 1983). Effortful control is conceptually similar to the cognitive inhibitory control component of the working memory skill coupling described by Diamond, 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 (Bell & Wolfe, 2004; 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 three 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 and colleagues (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. These findings are significant for the current study and support the legitimacy of using parent report for these constructs.

In a third study (Wolfe & Bell, 2004a) the similarities between the cognitive construct of inhibitory control and the temperament aspect of effortful control were explored. Relations were found between working memory scores and parent report of temperament using the CBQ. Importantly, positive associations were found between working memory 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 working memory 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 finding by Gerardi-Caulton (2000) and suggests that children who perform better on the working memory tasks also have a greater ability to regulate their anger and frustration.

Interestingly, working memory performance was negatively correlated to parental ratings of approach/anticipation, an unexpected but rather robust relation (Wolfe & Bell, 2004a). A consideration of the CBQ items that comprise the approach/anticipation scale may provide some insight into this negative association. 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 s/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 factor of the CBQ and performance on inhibitory control tasks used by Casey and colleagues (e.g., Casey et al., 1997). Importantly, the Surgency 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 more cognitive capacity to process other information. The negative relation between working memory 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 working memory. Perhaps, these high working memory children either do not get as enthusiastic about upcoming events or treats, or more likely, they do, but they have acquired the self-regulation skills necessary to be excited but to also focus their attention to the task at hand.

The current study, therefore, investigated the developmental relations between executive processing and several 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). Given the strong association between working memory performance and the approach scale of the CBQ, the Surgency factor and its component scales were also included in the analyses. The Surgency factor is comprised of approach/anticipation (i.e., the amount of excitement and positive anticipation for expected pleasurable activities), activity level (i.e., the level of gross motor activity including rate and extent of locomotion), high intensity pleasure or sensation seeking (i.e., the amount of pleasure of enjoyment related to situations involving high stimulus intensity, rate, complexity, novelty, and incongruity), and a negative contribution from shyness (i.e., the slow or inhibited approach in situations involving novelty or uncertainty). The impulsivity scale (i.e., the speed of response initiation) and the anger/frustration scale (i.e., the amount of negative affect related to interruption of ongoing tasks or goal blocking) were also included due to their conceptual relation to the other constructs of interest in this study.

The following temperament research questions were addressed: Is there an increase in Effortful Control and a decrease in Surgency across these three age groups? Working memory and temperament were found to be related for a group of 4½-year-olds, does this association hold for the other two age groups? The temperament scales that comprise the Effortful Control factor were expected to be positively related to working memory performance, and those scales that comprise the Surgency factor were expected to be negatively related to working memory performance across all three age groups. Another research question regarding working memory and temperament was that if these associations do in fact exist, do they change (e.g., increase or decrease in strength) across these three age groups? With regard to the explanation of variance in working memory function, can Wolfe and Bell (2004a, 2004b) be replicated such that the approach/anticipation scale is a valuable associate of working memory function? Likewise, is any other temperament dimension of interest (e.g., inhibitory control) of value in the explanation of variance in working memory function? Further, if either or both of the two previous questions are answered in the affirmative, do the resultant variable(s) explain variance in working memory function above and beyond the age variable? The final question involving age, working memory function, and temperament was: Is there an interaction effect such that the temperament variables of interest provide a meaningful explanation of variance in working memory function at one age but not at another?

Associations with Language. No account of the development of regulatory mechanisms – either cognitive or emotional – would be complete without the consideration of linguistic development. In fact, it has been suggested that one link between cognitive inhibitory control and emotional inhibitory control is the development of language (Ruff & Rothbart, 1996) and the development of private speech in particular (Berk, 1992; Vygotsky, 1962).

With regard to executive processing, there appears to be an association – both predictive and concurrent – 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 five (Rose, Feldman, Wallace, & Cohen, 1991). Likewise, phonological working memory scores of 3- to 4-year-old children have been associated with verbal fluency or speech production. Specifically, children with high working memory abilities produce more complex spoken language than children with low working memory abilities (Adams & Gathercole, 1995). Complementing these studies, a strong association has also been indicated between working memory and language receptivity (Wolfe & Bell, 2004a, 2004b). Specifically, the children with the highest working memory scores also had the highest language achievement as measured by the Peabody Picture Vocabulary Test (PPVT-III). 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.

Further, theorists have suggested an association between self-regulatory aspects of temperament qualities and the development of language. 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).

Incidentally, the influence of temperament characteristics on the development of language abilities has been supported (Dixon & Shore, 1997; Dixon & Smith, 2001; Kubicek et al., 2000; 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). Although, an opposing perspective (that has previously been described) exists in which children with a neutral affect as opposed to a highly positive or highly negative one are at an advantage for linguistic development (e.g., Bloom, 1993).

Thus, this study attempted to replicate Wolfe & Bell (2004a, 2004b) by investigating the working memory and language receptivity association with 4½-year-olds and to also extend this work to include younger age groups (i.e., 3½- and 4-year-olds). The current study also included a language expressivity or a verbal fluency measure. As previously mentioned, language expression has been related to working memory and also has been associated with frontal functioning (Leonard, 1997; Luciana & Nelson, 2003).

With regard to linguistic abilities then the following research questions were posed: Is there an increase in language comprehension and expressivity with age? As with Wolfe and Bell (2004, 2004b), are either or both of the language measures meaningful in the explanation of variance in working memory function for these three age groups of preschool children? Further, does the language variable explain variance above and beyond that of the age variable? Finally, is there an interaction effect between age and language such that the language-working memory relation exists at one age but not another? Or does the nature of the relation change (e.g., increase or decrease in strength) across the three age groups?

Collective Contributions to Working Memory Function

In attempt to replicate the multivariate findings of Wolfe and Bell (2004a) and extend these findings to include the age variable, this study considered the collective contribution of all variables (i.e., age, brain electrical activity, temperament, and linguistic ability) in explanation of variance in working memory function in early childhood. These three specific research questions were addressed: What proportion of variance is explained with the inclusion of all variables concomitantly? Is there unique variance explained by each? What variable is the strongest and most valuable predictor when considered with the others?

A Summary of Research Questions

There were two main goals of this study. The first goal of this study focused on the regional differences in baseline-to-working memory task brain electrical activity and specifically investigated the hypothesis that there would be an increasing specificity of task EEG power between 3½ and 4½ years of age. The first research question addressed was: Is there an increasing specificity of baseline-to-task EEG power with age such that multiple (e.g., frontal and posterior) brain regions increase in power from baseline-to-task for the 3½-year-olds but only one region (i.e., medial frontal) increases in power for the 4½-year-olds?

The second goal of this study was to investigate the sources of variability in working memory function and to specifically examine the contributions of task-related brain electrical activity, the regulatory and surgent dimensions of temperament, and linguistic ability to the prediction of working memory performance. This second study objective included an investigation of the relation between working memory and each of these variables (1) separately,

(2) in conjunction with age, and (3) collectively to examine any multivariate contributions to the explanation of variance in working memory function in early childhood.

Age. Each cognitive variable (i.e., the working memory tasks and both language measures) was examined to determine if there were differences on each for the three age groups. An increase in performance on the working memory tasks and the language measures were expected. Also, the value of the age variable in the explanation of variance in working memory function was assessed. That is, does age account for a significant portion of variance on working memory tasks? The previous literature review suggests that this is the case. One major goal of the current study was to determine if there are any other variables (e.g., brain electrical activity, temperament, or linguistic ability) that might be equally, or more, meaningful in association with working memory function.

Brain Electrical Activity. With regard to brain electrical activity and its associations with working memory function, the following questions were posed: (1) Does left medial frontal EEG power explain a significant portion of variance in working memory performance? (2) If so, does this variable explain unique variance above and beyond the age variable? (3) Finally, is there an interaction effect such that this EEG-working memory performance relation holds for one age but not another?

Temperament. With regard to the regulatory and surgent dimensions of temperament, the following research questions were addressed: (1) Is there an increase in the regulatory dimension (i.e., Effortful Control) and a decrease in the surgent dimension (i.e., Surgency) of temperament with age? (2) With regard to the associations between temperament and working memory function, does the approach/anticipation dimension of temperament explain a significant portion of variance in working memory function? (3) Does any other temperament dimension of interest (e.g., inhibitory control) meaningfully relate to working memory performance? (4) If so, does this variable contribute to the explanation of variability in working memory performance above and beyond the age variable? (5) Finally, is there an interaction effect between age and temperament such that the temperament-working memory relations exist (or are different) at one age but not at another?

Language. With regard to the linguistic measures, (1) does language comprehension and expressivity increase with age? (2) Do either or both of these language variables contribute meaningfully to the explanation of variance in working memory function? (3) Do either or both of these variables explain variance above and beyond that explained by age? (4) Finally, is there an interaction between age and language such that the working memory-language relation exists at one age but does not at another? (5) Or is the relation stronger at one age than another?

Collective Contributions. The final research question of this study was how do all of these aspects of development – age, physiology, temperament, and language – work together to predict working memory function in early childhood? Specifically, (1) how much variance in working memory function can be explained by all of these variables concomitantly? (2) Do each of these variables contribute unique variance? (3) Is one variable more valuable than the others in the explanation of variance in working memory function in early childhood?

Method

Participants

Three groups of children – 20 3½-year-olds (41-43 months), 20 4-year-olds (47-49 months), and 21 4½-year-olds (53-55 months) – and their parents were recruited for participation in this study. One hundred and twenty-five families listed in the Developmental Science Database with children nearing these ages were sent a recruitment letter introducing the study and alerting them of a phone call to follow regarding participation in the study. See Appendix A. Approximately one week after receiving the recruitment letter, the parents will were contacted by phone, the study was described further and discussed, and visits were scheduled for those families who were interested. Fifty-five families were successfully recruited via this method with 30 of these families having previously participated in research at Virginia Tech. Similar procedures were followed for recruiting from preschool and daycare facilities in the New River Valley area, except parents were given information to contact us as we did not have their names or contact information. Specifically, one hundred and fifty recruitment letters were sent home with children of the appropriate age; the parents were given our contact information, such as the lab phone number and email address, and were instructed to notify us if they were interested in participating in the study. See Appendix B. Only six families were successfully recruited by this method. Demographic information for all participants is listed in Table 1.

Procedures

Children and their parents visited the Developmental Cognitive Neuroscience Lab located in Williams Hall on the campus of Virginia Tech. 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. See Appendices C and D for the parent consent and child assent forms. A series of tasks that involve the cognitive skills of working memory and inhibitory control were administered. The tasks that did not require gross motor movement on the part of the child were accomplished while electroencephalographic (EEG) recording was done. The accompanying parent was seated beside and slightly behind the child throughout the duration of the visit. The behavioral and physiological measures are discussed in turn.

Warm-up Exercises

The first two tasks were played without physiological recordings and served as "warm-up" or "ice-breaker" exercises through which the children became more comfortable in the lab and with the experimenter. Both of these tasks required the children to pay attention to a given set of rules, remember these rules throughout the task, and to inhibit a dominant response tendency. Both of these tasks have been used in the developmental literature.

Simon-says Task. The first laboratory task was a simplified version of the traditional Simon-says game and closely followed the Bear/Dragon procedure described by Carlson, Moses, and Breton (2002; adopted from Reed, Pien, & Rothbart, 1984) except a Pig puppet and a Bull puppet were used. To begin, the experimenter asked the children to imitate the following 10 actions: stick out your tongue; touch your ears; touch your teeth; touch your eyes; clap your hands; touch your feet; touch your head; touch your tummy; touch your nose; and wave your hand. The experimenter then introduced the two puppets. The first was described as a "nice Pig"; "So when he talks to us, we will do what he tells us to do." These were the activation trials. The second puppet was described as a "mean Bull"; "So when he talks to us, we won't listen to him. If he tells us to do something, we won't do it." These were the inhibition trials. Practice trials followed, in which the experimenter moved the Pig's mouth and said (in a high-pitched voice), "Touch your nose," and then moved the Bull's mouth and said (in a low, gruff voice), "Touch your tummy." Children passed the practice test if they followed the Pig's command but ignored the Bull's. Difficulty passing the Bull test trial (i.e., failing two practice trials) resulted in the assistance of a second experimenter (or the mother) to play the game with child and to remind the child to inhibit. Ten test trials followed (5 Pig trials and 5 Bull trials, alternating order) in which children were given no assistance but were praised when the experimenter felt they needed encouragement. The children were reminded of the rules after 5 trials regardless of performance. The total administration time for this task was approximately three minutes. This task was videotaped and later scored for accuracy of inhibitory performance. Specifically, the success of the child to delay was coded (successful or unsuccessful). The final score was included a contribution from all five trials with complete success resulting in 100; with 4 successful trials out of 5 resulting in a score of 80; with 3 successful trials out of 5 resulting in a score of 60; 2 successful trials out of 5 resulting in a score of 40; 1 successful trial out of 5 resulting in a 20; and 0 successful trials out of 5 resulting in a score of 0. Interrater reliability was calculated for 20 percent of the sample; Kappa for the success of the child to inhibit performance was .9184.

M&Ms Task. The second game to serve as an "ice breaker" game but that also required the skills of interest was the M&Ms task. This task, also known as the tongue task, was taken from a battery of tasks to assess effortful control abilities of young children (Kochanska et al., 2000). The M&Ms 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 seconds). The total administration time for this task was approximately three minutes. The success of the child to delay was coded (successful or unsuccessful). The final score included a contribution from each trial with complete success resulting in a score of 100, with 3 successful trials out of 4 resulting in a score of 75; with 2 successful trials out of 4 resulting in a score of 50; with 1 successful trial out of 4 resulting in a score of 25; and with no successful trials resulting in a score of 0. This task was also videotaped and later scored for accuracy of inhibitory performance. Interrater reliability was calculated for 20 percent of the sample; Kappa for the success of the child to inhibit eating the M&M was .90.

Physiological Measures

The next segment of the visit included the administration of the working memory tasks and included the EEG recording. Specifically, EEG measures were accomplished during two minutes of eyes-open baseline period and during three tasks. The two minutes of baseline was collected as the children watched a specific *Finding Nemo* clip. EEG was also collected during the three cognitive measures that did not require considerable gross motor movement: Two working memory tasks (i.e., the day-night and the yes-no tasks to be described in the next section) and during the language expressivity measure (to be described in the Language Assessment section). EEG electrodes were applied as the child was entertained by a research assistant and an age appropriate computer game.

EEG. 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 was inserted into each recording site and the scalp lightly rubbed. Electrode impedances were measured and were accepted if they are below 10K ohms. The electrical activity from each lead was amplified using separate SA Instrumentation Bioamps, band passed from 0.1 Hz to 100 Hz, and digitized online at 512 samples per second to prevent aliasing. Activity for each lead was displayed on a Pentium computer using SnapMaster acquisition software.

The EEG data were examined and analyzed using software developed by James Long Company (Canoga Lake, NY). First, the data was rereferenced via software to an average reference configuration and then artifact scored for eye movements (using Fp1 and Fp2 as a guide) and gross motor and muscle movements through visual examination. A little more than 40 percent of the EEG data – including both baseline (43 percent) and task (45 percent) epochs – was artifact-rejected and was eliminated from all subsequent analyses. These percentages of artifact-rejected data are comparable to those found in previous EEG research with preschool children (Wolfe & Bell, 2004a). The amount of data remaining in the analyses (i.e., artifact-free data) was unrelated to all CBQ temperament dimensions except shyness; shyness was negatively related to both baseline and task artifact-free EEG (baseline $r = -.279$, $p = .058$; task $r = -.305$, $p = .037$). These negative relations suggest that shy children contributed less artifact-free data than children who were rated less shy by their parents. The remaining artifact-free data were analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-sec width and 50% overlap. Power was computed for the 6- to 10-Hz frequency band, the dominant frequency for preschool children (Marshall, Bar-Haim, & Fox, 2002) and a band that has shown associations with individual differences in cognitive processing with these two populations (Wolfe & Bell, 2004a, 2004b). The power was expressed as mean square microvolts, and the data transformed using the natural log (ln) to normalize the distribution. It is important to note that 11 3½-year-olds (9 children either did not accept the EEG equipment or the application of gels), 19 4-year-olds (1 child did not accept the EEG equipment), and 20 4½-year-olds (1 child did not accept the EEG equipment) contributed EEG data to these analyses.

Working Memory Tasks

Three tasks were used to investigate the children's working memory – requiring controlled attention and processing and inhibitory control – abilities: the day-night Stroop-like task, the yes-no task, and the Dimensional Change Card Sort (DCCS). Two of these tasks – the day-night and the yes-no tasks – were accomplished during EEG recording. All three of these tasks required the child to pay attention to a set of rules, remember the rules throughout the task, and to inhibit a dominant response tendency. Each has been used in the developmental literature.

Day-night Stroop-like Task. The day-night Stroop-like task has been used in the developmental literature with children ages 3½ to 7 years of age and is believed to involve the dorsolateral prefrontal cortex (Diamond & Taylor, 1996; Diamond et al., 1997; Gerstadt et al., 1994). One set of laminated cards (4in x 6in) was used. See Appendix F. The children were instructed to say “day” when shown a moon card and to say “night’ when shown a sun card. The children were given two learning trials during which they were praised or corrected, then 16 test trials were administered, eight with the sun card and eight with the moon card arranged in a pseudorandom order. The series of stimulus cards were presented as follows: D, N, N, D, N, N, D, D, D, N, D, N, N, D, D, N. No feedback was given during testing. The total administration time for this task was approximately three minutes. The percentage correct was calculated. The percentage of agreement between two coders for 20 percent of the sample for the day-night task was 93.34 percent. EEG recording was collected during this task.

Yes-no Task. The yes-no task has been used in the developmental literature with 4½-year-old children and has been associated with electrical activity in the medial frontal scalp locations (Wolfe & Bell, 2004a, 2004b). Similar to the day-night testing procedure, the child was instructed to say “no” when the experimenter nods her head yes and to say “yes” when the experimenter shakes her head no. Again, the children were given two learning trials during which they were praised or corrected, then 16 test trials were administered, with eight head nods and eight head shakes arranged in a pseudorandom order. The series of stimulus gestures were presented as follows: Y, N, N, Y, N, N, Y, Y, Y, N, Y, N, N, Y, Y, N. No feedback was given during testing. The total administration time for this task was approximately three minutes. The percentage correct was calculated. The percentage of agreement between two coders for 20 percent of the sample for the yes-no task was 96.15 percent. EEG recording was collected during this task.

Dimensional Change Card Sort Task. The Dimensional Change Card Sort task has been used in the developmental literature to assess executive functioning and rule use in young children (DCCS; Zelazo et al., 1996). One set of laminated cards (11 cm x 7 cm) was used. There were two target cards (e.g., a blue car and a red flower) to be matched and 14 test cards (e.g., 7 blue flowers and 7 red cars; See Appendix G). All test cards could be sorted differently if one were sorting by color or shape. The card sort task involved a preswitch phase and a postswitch test phase. The dimension (color or shape) that was relevant during the preswitch phase was counterbalanced and crossed with age.

Children were seated at a small table across from the experimenter. One target card was affixed to each of two small trays. Then, the experimenter gave the child rules for separating test cards by one dimension (e.g., “All the red ones go here, but only blue ones go in that box.”) and sorted one test card face down into each tray. The child was required to sort the remaining 12 test cards. On each of the five preswitch trials, the experimenter told the child the preswitch rules, randomly selected a test card, labeled the card by the relevant dimension only (e.g., “Here’s a red one”), and asked the child, “Where does this go in the ________ (e.g., color) game?” The child was required to place the card face down into one of the trays and then was not told whether or not he/she sorted the card correctly. When the child completed five trials, the child was asked to stop playing the first game and was asked to switch to a new game. The child was told, for example, “Okay, now we’re going to switch and play a new game, the shape game. We’re not going to play the color game any more. No way. We’re going to play the shape game. The shape game is different.” The child was then given five postswitch trials that were identical to the preswitch trials except that on each trial the child was told the rules for sorting by the other dimension (e.g., shape), and the child was not told whether or not she sorted the cards correctly. The experimenter simply said, “Okay”, and proceeded to the next trial.

Finally, after five or six postswitch trials, the child was given two additional trials, with each trial involving two knowledge questions and one action question. For the two knowledge questions, children were asked about each of the two postswitch rules: “Where do to the _______ (e.g., cars) go in the _________ (e.g., shape) game? Where do the__________ (e.g., flowers) go?” In response to each question, the child was required to point unambiguously to one of the two trays. For the action question, the child was given a sorting trial that was similar to the postswitch trials in the card sort proper. The child was told, “Play the ______ (e.g., shape) game,” given a test card that was labeled by the relevant dimension only, and asked, “Where does this go in the _______ (e.g., shape) game?” As in the card sort proper, the child was required to place the card into one of the two boxes. The number of correct sorts was scored and categorized as the number of preswitch correct and the number of postswitch correct. The number correct of the final four sorts, following the knowledge questions, was scored separately. The percentage correct of postswitch sorts was used in these analyses. Interrater reliability was calculated for the postswitch trials for 20 percent of the sample; Kappa for the success of the child to sort correctly was .9227. The total administration time of this task was approximately seven minutes.

Language Assessment

The final segment of the visit consisted of two language assessment measures – one measuring language receptivity/comprehension and one measuring the child’s expressive vocabulary skills. To examine the children's expressive vocabulary abilities, the children were given an age appropriate verbal fluency measure. Traditional verbal fluency measures used with adults require adults to list as many words as possible that begin with a particular letter of the alphabet (e.g., Thurstone's Word Fluency Test, Milner, 1964). This procedure would be too difficult for young children, however. The current procedure closely followed that described by Welsh et al. (1991) and asked children to produce as many words as they can by semantic category (e.g., animals and food) within 40 seconds. This task has been used with children ages 3 to 12 years of age. This task was scored by the total number of correct words given for the two categories. The percentage agreement between two coders for the number of words produced for 20 percent of the sample was 96.51 percent.

The Peabody Picture Vocabulary Test – III (PPVT-III; Dunn & Dunn, 1997) was administered to the children to examine receptive vocabulary and verbal comprehension. The PPVT-III is a nationally standardized instrument. The children's raw sores were used in all analyses.

Temperament Assessment – Parent Report

The Children's Behavioral Questionnaire (CBQ; Rothbart et al., 2001) was used to examine parent perceptions of child temperament as well as any relations between these parental perceptions and the children's cognitive skills assessed in this study. The CBQ is a 196-item questionnaire designed to measure general patterns of behavior in children ages 3 to 7 years of age. Three broad factors are consistently yielded with this measure: Surgency (approach, high-intensity pleasure, activity level, and a negative contribution from shyness), negative affectivity (discomfort, fear, anger/frustration, sadness, and a negative contribution from soothability), and effortful control (inhibitory control, attentional focusing, low-intensity pleasure, and perceptual sensitivity).

The questionnaire was mailed to the parents prior to and then was collected at the laboratory visit. Although all CBQ temperament scales were collected, the scales of particular interest are the ones that comprise the Effortful Control factor and the Surgency factor; an additional scale of interest includes the anger scale from the negative affectivity factor. Past research has shown a relation between the CBQ Surgency scale of approach and performance on these types of cognitive tasks. The same is true for the anger scale with implications for the regulation of affect and underlying neural processes such as those that are associated with working memory skills.

Parent Information

General information, such as parent age, education level, ethnicity, and handedness, was also requested from the parents. See Appendix E. This information is displayed in Table 1.

Results

There were two main goals of this study. The first goal of this study focused on the regional differences in baseline-to-working memory task brain electrical activity and specifically investigated the hypothesis that there would be an increasing specificity of task EEG power between 3½ and 4½ years of age. The second goal of this study was to investigate the sources of variability in working memory function and to specifically examine the contributions of task-related EEG, the regulatory dimensions of temperament, and linguistic ability to the prediction of working memory performance. This second study objective included an investigation of the relation between working memory and each of these variables (1) separately, (2) in conjunction with age, and (3) collectively to examine any multivariate contributions to the explanation of variance in working memory function in early childhood.

The Increasing Specificity of Brain Electrical Activity Hypothesis

The first EEG analysis tested for regional power differences between baseline and working memory task with the expectation that there would be an increasing specificity of task EEG power at some point between age 3½ and age 4½. Baseline EEG was accomplished while a children’s video was played and resulted in an average of 62 seconds of artifact-free data. The EEG data collected during two working memory tasks (i.e., day-night Stroop and yes-no) were combined and yielded on the average 73 seconds of artifact-free task data. To investigate the specificity hypothesis, a repeated-measures MANOVA was performed on the ln (6-10Hz) 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 age group (i.e., age 3½, age 4, and age 4½).

This analysis yielded main effects for both condition, F (1, 43) = 13.537, $p = .001$, and region, F (7, 37) = 27.824, $p < .001$. These main effects were superceded by a condition x region interaction, F (7, 37) = 3.819, $p = .003$. Because there were specific hypotheses made about the baseline-to-task activation patterns for the different regions and to aid interpretation of the two-way interaction between condition and region, separate MANOVAs were performed on the EEG power values for each of the eight regions. The adjusted p value was $\leq .006$ (.05/8 = .006). For the MANOVAs for each region, condition (i.e., baseline and task) and hemisphere (i.e., left and right) were the within-subjects factors and age (i.e., age 3½, age 4, and age 4½) was the between-subjects factor. These later analyses revealed no main effects or interactions for the lateral frontal, central, parietal, or occipital regions, all *p*s > .006. See Table 2.

Frontal pole (Fp1/Fp2). There was a main effect for condition with all children exhibiting greater EEG power values during task than during baseline, *t*(46) = 4.52, *p* < .001. This effect was superceded by a condition x hemisphere interaction with the left frontal pole region showing an increase in power from baseline-to-task, *t*(46) = -5.33, *p* < .001; although, in the post-hoc analysis, a significant increase was seen for the right frontal pole region as well, *t*(46) = -3.33, *p* = .002.

Medial frontal (F3/F4). There was a main effect for condition with all children exhibiting greater EEG power during task than during baseline, *t*(47) = -3.660, *p* = .001.

Anterior temporal (T3/T4). There was an age x hemisphere interaction with the right anterior temporal scalp location at age 3½ showing greater baseline and task power than the left anterior temporal scalp location at that age only, age 3½ *t*(10) = -3.257, *p* = .009.

Posterior temporal (T5/T6). There was a main effect for condition with all children exhibiting greater EEG power during task than during baseline, *t*(47) = -4.919, *p* < .001.

Although there was only one significant effect including the age variable (an age x hemisphere at the anterior temporal region) in the previous analyses, there were specific hypotheses made about the specificity of baseline-to-task EEG power with age. Therefore, an additional set of analyses were performed investigating baseline-to-task power differences at each age for the four regions which had yielded significant findings from the previous analyses (i.e., frontal pole, medial frontal, anterior temporal, and posterior temporal). The adjusted *p* value was ≤ .004 (4 regions x 3 age groups = 12 analyses; *p* = .05/12 = .004). See Table 3.

Frontal pole (Fp1/Fp2). There was a main effect for condition at age 4 only with greater power values during the tasks than during baseline for this age group, $t(16) = 3.722$, $p = .002$. See Figure 1.

Medial frontal (F3/F4). There were main effects for condition at age 4 and age 4½ with greater power values during the tasks than during baseline for these age groups, age 4 $t(17) = -3.50$, $p = .003$ and age 4½ $t(18) = -3.472$, $p = .003$. See Figure 2.

Anterior temporal (T3/T4). There was a main effect for condition at age 4 only as there were greater power values during the tasks than during baseline for this age group, $t(17) = 2.184$, $p < .001$. See Figure 3.

Posterior temporal (T5/T6). There was a main effect for condition at age 4 and age 4½ with greater power values during the tasks than during baseline for these age groups, age 4 $t(17) = -4.653$, $p < .001$ and age 4½ $t(18) = -3.289$, $p = .004$. See Figure 4.

To summarize the analyses investigating the increasing specificity of task EEG power hypothesis, for the entire group of children there was an increase in baseline-to-task EEG power for the frontal pole, medial frontal, and posterior temporal scalp locations and an age x hemisphere effect for the anterior temporal region. Hypotheses-driven post-hoc analyses revealed increases in baseline-to-task EEG power for four regions in the 4-year-olds (i.e., frontal pole, medial frontal, anterior temporal, and posterior temporal) and increases in baseline-to-task power for two regions in the 4½-year-olds (i.e., medial frontal and posterior temporal). No condition effects were found for the 3½-year-old age group.

Sources of Variability in Working Memory Function

The second set of analyses addressed the second goal of the study – to investigate the sources of variability in working memory function. Specifically, these analyses examined working memory function in association with brain electrical activity, temperament, language, and age. This section begins with an overview of the working memory data and investigates the association between working memory performance and the age variable. The remainder of the section replicates this format investigating associations between working memory performance and brain electrical activity, temperament, and language with the age variable considered along with each. This section concludes with a multivariate approach to explaining variability in working memory performance.[1]

Age. First, to investigate the relations between all variables included in the current study, Pearson correlations were calculated for each variable representing the constructs of working memory, language, temperament, and brain electrical activity. This was done separately for each age group. See Table 4 for the age 3½ data, Table 5 for the age 4 data, and Table 6 for the age 4½ data.

To highlight and examine the relations among the working memory measures, Pearson correlations were calculated between all five working memory tasks (i.e., tongue task, Simon-says task, day-night Stroop task, yes-no task, and the DCCS) for the whole sample of children and then illustrated again separately for each age group. Positive associations among the working memory measures were hypothesized for the whole sample and for each age group. This hypothesis was partially supported. For the whole sample, all tasks were positively related with the exception of three comparisons. See Table 7. For each age group, however, the patterns of association were different. At age 3½, only one of the ten comparisons was found to be statistically significant, and this association was not in the hypothesized direction. At age 4, four of the ten comparisons were found to be statistically significant, and all of these were in the hypothesized direction. At age 4½, nine of the ten comparisons were statistically significant in the hypothesized direction. See Table 8.

To assess the age-related changes in working memory function, a working memory score was computed by averaging the scores of all five working memory tasks (i.e., tongue task, Simon-says task, day-night Stroop task, yes-no task, and the DCCS); this score will be referenced as WM_5 with the "5" subscript representing the inclusion of five working memory tasks in this particular score. An analysis of variance (ANOVA) was performed on the resultant WM_5 score with age as the independent variable. An increase in working memory function (indicated by an increase in task performance) was expected with age, as children age 4½ were hypothesized to have a higher WM_5 score than children age 4 who in turn were expected to have a higher WM_5 score than children age 3½. This hypothesis was not supported with these data. The results of the ANOVA suggested that there were no differences between the WM_5 scores of these three age groups, F (2, 43) = 1.86, $p > .05$. Descriptive statistics for all five working memory tasks as well as the newly created working memory score are illustrated in Table 9.

The age variable was hypothesized to account for a significant portion of the variance in the working memory function. This hypothesis was tested by a regression procedure in which the aforementioned WM_5 score was the dependent variable and age (through a dummy coding procedure) was the independent variable. As reflected in the above ANOVA, the results of this analysis indicated that age was not a significant predictor of the WM_5 score accounting for only 8 percent of the variance in working memory function ($R = .282$; $R^2 = .08$).

Brain Electrical Activity. To examine the value of EEG power in the prediction of working memory function in early childhood a regression analysis was performed with the WM_5 score as the dependent variable and task EEG power from the left medial frontal region (F3) as an independent variable. Based on previous work in our lab (Wolfe & Bell, 2004), it was hypothesized that the EEG power from this specific scalp location would be predictive of working memory function. The age variable was entered as the first step, the left medial frontal EEG (F3) was added in the second step, and then the interaction term between age and left medial frontal EEG was added in the final step. The hypothesis that left medial frontal EEG would predict working memory function was partially supported. Although the model including only age was not significant, the results of the analysis including age and left medial frontal EEG power approached significance, F (3, 42) = 2.683, p = .059, suggesting that task-related EEG power from the left medial frontal scalp location was a meaningful variable in the explanation of variance in working memory function. The interaction between age and left medial frontal EEG was not significant. See Table 10.

To determine if any other task EEG power values were predictive of working memory function, an exploratory backward elimination regression procedure was performed with the WM_5 score as the dependent variable and the task EEG power values found to be significant in the first set of EEG analyses (i.e., Fp1, Fp2, F3, F4, T3, T4, T5, T6) entered as the independent variables. One variable approached significance as a meaningful associate of working memory function in the final model – the left medial frontal scalp location (F3), F (1, 43) = 3.002, p = .09.

Temperament. Pearson correlations were calculated between the CBQ scales of interest including the scales of the Effortful Control factor (i.e., inhibitory control, attention focusing, low-intensity pleasure, and perceptual sensitivity), the Surgency factor (i.e., approach, activity level, high pleasure, and shyness – which makes a negative contribution), and the impulsivity and anger/frustration scales for the entire sample. Positive associations among scales that comprise each factor were hypothesized; that is, all scales that comprise the Effortful Control factor and those that comprise the Surgency factor were expected to be positively related. Negative associations were expected between the scales of the Effortful Control factor and the Surgency factor; that is, scales that comprise the Effortful Control factor were expected to be negatively related to those scales that comprise the Surgency factor. These hypotheses were largely supported. See Table 11.

Two ANOVAs were performed on the Effortful Control and Surgency factor scores to determine if there was an increase in the regulatory dimension or a decrease in the surgent dimension of temperament with age. The results of this analysis yielded null findings for both CBQ factors, specifically Effortful Control F (2, 56) =.466, $p > .05$ and Surgency F (2, 56) = .029, $p > .05$.

To determine if the nature of the associations between temperament and working memory function is different for these three age groups, Pearson correlations were calculated between the regulatory dimensions of temperament and the five working memory tasks and for the overall all WM_5 score separately for each age group. Positive associations between the Effortful Control scales of the CBQ and the working memory tasks were hypothesized. Negative associations between the scales comprising the Surgency factors and the working memory tasks were expected. The strength of these associations was hypothesized to increase with age. These hypotheses were partially supported. Specifically, a cluster of positive associations was found between the working memory tasks and the Effortful Control scales largely for the 4-year-olds, and a cluster of negative associations was found between the working memory tasks and the Surgency scales for the 4½-year-olds. There was no consistent or discernable pattern for the 3½-year-olds. See Table 12.

Wolfe and Bell (2004) found the approach scale of the CBQ to be a predictor of working memory performance at age 4½ through a discriminant classification analysis. To examine if the approach dimension of temperament was predictive of working memory function in the current study, a regression analysis procedure was performed with the WM_5 score as the dependent variable, the age variable as the first independent variable, the approach scale as the second independent variable, and the interaction between age and approach as the third independent variable. The results of these analyses were not significant, all *F*'s < 1.864, all *p*'s > .167.

To explore if another regulatory dimension of temperament, specifically inhibitory control, was related to working memory function, a regression procedure was performed with the WM5 score as the dependent variable, the age variable as the first independent variable, the inhibitory control scale as second factor, and an interaction term between age and inhibitory control as the third independent factor. The results of this analysis revealed that the model including age and inhibitory control as independent variables approached significance, *F* (3, 42) = 2.42, *p* = .097; and the model including the interaction between age and inhibitory control was statistically significant, *F* (5, 40) = 2.647, *p* = .037, suggesting that the nature of the relation between inhibitory control and working memory is different for these three groups of children. See Table 13.

Language. To examine the relation between the two language measures, a Pearson correlation was calculated for the language receptivity measure and the verbal fluency measure. These two language measures were hypothesized to be positively correlated. This hypothesis was supported. The language receptivity and verbal fluency measures were positively correlated, *r* = .38, *p* = .004.

To examine if there was an increase in language receptivity or verbal fluency ability with age, two ANOVAs were conducted on the language scores with age as the independent variable. Both language measures were expected to increase with age. This hypothesis was partially supported. There was a difference between the language receptivity scores (i.e., PPVT-III scores) across the three age groups, F (2, 43) = 3.667, p = .034 (age 3½ M = 62.09, SD = 11.83; age 4 M = 63.12, SD = 10.76; age 4½ M = 73.06, SD = 14.67). Post-hoc analyses revealed marginally significant differences between the 4½ -year-olds and both other age groups, (age 3½ and 4 ½ M_d = 10.96, SE = 4.8, p = .08; age 4 and 4 ½ M_d = 9.93, SE = 4.29, p = .07). There were no differences between the age groups on the verbal fluency measure, F (2, 43) = 1.07, p > .05, age 3½ M = 4.0, SD = 3.34; age 4 M = 5.47, SD = 2.98; and age 4½ M = 5.39, SD = 2.30.

To examine if the language receptivity measure was a valuable predictor of working memory function in early childhood, a regression analysis was performed with the WM_5 score as the dependent variable, with age as the first independent variable, with the Peabody score as the second independent variable, and the interaction term between the age variable and the Peabody score as the third independent variable. This regression analysis resulted in a significant model, F (3, 42) = 9.194, p < .001, accounting for 39.6 percent of the variance in working memory function. Although the overall equation including the interaction term between age and language receptivity was significant, F (5, 40) = 5.662, p < .001, the interaction did not appear to be contributing meaningfully to the explanation of variance in working memory performance. See Table 14.

The association between language and working memory was hypothesized to increase with age. This hypothesis was supported for the language receptivity measure. A regression analysis with the WM_5 score as the dependent variable and the language receptivity measure as the independent variable was performed for each age group. Language receptivity was a valuable predictor or working memory at all ages and further the strength of the association appeared to increase across the three age groups. See Table 15.

Collective Contributions to Working Memory Function. The final analysis of this study addressed the prediction of working memory function in early childhood using multiple variables as predictors. A hierarchical multiple regression procedure was performed with the WM_5 score as the dependent variable and the variables from each construct that were found to be associated with working memory performance (i.e., age, left medial frontal EEG, the temperament scale of inhibitory control, and language receptivity). Age was entered into the analysis first, then EEG, then the temperament scale, and then the language measure. With the exception of the first model (which included age only), all models were significant (model three including temperament was only marginally significant) suggesting that each variable contributed to the explanation of unique variance in working memory function. With the inclusion of the language receptivity measure in the final model, however, all other measures diminished their contribution to the explanation of variance in working memory function. See Table 16.

Finally, to determine which factor of these was the best and most meaningful predictor of working memory performance, a regression procedure was employed in which age, medial frontal EEG, the temperament scale of inhibitory control, and the language receptivity measure were entered, and a forward regression was performed. Not surprisingly, the results of this analysis suggested that the language receptivity measure was the strongest, most meaningful predictor of working memory function in early childhood, F (1, 44) = 28.634, $p < .001$, accounting for 39.4 percent of the variance ($R = .628$; *Beta* = .628, $t = 5.351$, $p < .001$).

Discussion

The Increasing Specificity of Brain Electrical Activity Hypothesis

With regard to the first goal of the study, there was some support for the increasing specificity of brain function in early childhood hypothesis as there was an increasing specificity of task EEG power after age 4. Specifically, there was increase in baseline-to-working memory task EEG power for four regions at age 4 (i.e., frontal pole, medial frontal, anterior temporal, and posterior temporal) but a statistically significant increase for only two regions at age 4½ (i.e., medial frontal and posterior temporal). This finding coupled with the previous Wolfe and Bell (2004a) result of a baseline-to-working memory task EEG increase for the medial frontal region at age 4½ lends support to the increasing specificity hypothesis. This is an exciting finding and suggests that the reorganization of the brain, specifically the specialization of function, is occurring during the early childhood years at the same time many higher order cognitive advances are being made. Further, it is exciting that this specialization can be captured through electroencephalographic measures. The pattern of electrical activation revealed for the 4½-year-old children is similar to that found in *f*MRI work with 7- and 8-year-old children (Casey et al., 1997) and suggests the involvement of the dorsolateral prefrontal cortex during working memory task performance.

This analysis found the scalp locations over the posterior temporal region to be involved in the cognitive processes associated with these working memory tasks. The posterior temporal scalp electrodes are located over an area that is mostly associated with the comprehension of speech and language, specifically Wernicke's area. An increase in brain electrical activity over the posterior temporal area is likely indicative of functioning of the auditory cortex that is specifically associated with language comprehension. This is a likely scenario as the working memory tasks used in this study were largely verbal tasks – the instructions were given verbally and must have been comprehended as such. These working memory tasks also required the children's responses to be in verbal form. Although Broca's area is most often associated with the production of speech, these two areas are heavily interconnected with neural pathways and an increase in electrical activity over the posterior temporal area lends support to this notion.

An inspection of the ln EEG (6-10 Hz) power values at age 3½ reveals them to be consistently higher than those of the two older age groups. This pattern of activation in which younger children have higher power values in the 6-10 Hz range is characteristic of the developmental pattern of EEG power from infancy to early childhood. Specifically, there is a developmental increase in this frequency power from infancy to early childhood, after which time a decrease in frequency power for some scalp regions occurs (Marshall, Bar-Haim, & Fox, 2002). This pattern of electrical activation is perhaps reflective of the spurts in brain growth at 3-to-10-months and again at 2-and-4-years, the proliferation of neural connections, and then the subsequent reduction of them through the pruning process (Bourgeois, 2001; Epstein, 1978).

Also interesting, baseline and task EEG power at age 3½ did not follow the pattern of activation as seen with the 4- and 4½-year-old children or even of that seen with infants. One possible explanation for the unique baseline-to-task activation patterns at age 3½ is that the working memory tasks used in this study may not have been tapping the same working memory construct in this age group as in the two older groups of children. Perhaps the inclusion of a more age appropriate task for the 3½-year-old children would have yielded differential patterns of baseline-to-task EEG power. Or perhaps an investigation of those high performing 3½-year-olds – compared to the lower performing 3½-year-olds – would yield baseline-to-task activation patterns similar to the older children. This later question is addressed in the Post-Hoc Analyses section of this document.

Sources of Variability in Working Memory Function

Age. Although age was hypothesized to be a strong predictor and meaningful variable in the explanation of variance in working memory function, the analyses investigating this association were not supportive of this expectation. Specifically, there were no statistically significant differences in working memory task performance across the three age groups of children, and the 3½ -year-old children’s (i.e., those 3½-year-olds who accepted all procedures and performed all tasks) performance was almost identical to the 4-year-old children’s performance. These data suggest then that there are children who may be younger in biological age (i.e., 3½-years) yet they are performing at a level comparable to those children who are older in biological age (i.e., 4- and 4½-years). With these data, age is truly a proxy variable, and the variability in working memory performance is better explained through individual differences in brain electrical activity and linguistic functioning.

Brain Electrical Activity. The value of using brain electrical activity, and specifically task-related EEG, in the explanation of variance in working memory function was demonstrated. The results of the regression procedure implicated the left medial frontal region (F3) in the explanation of variance in working memory function for these preschoolers. Importantly, this specific scalp location was found to be associated with working memory performance in a previous study with preschool-aged children (Wolfe & Bell, 2004a). The brain electrical activity represented by the left medial frontal power is likely associated with the functioning of the dorsolateral prefrontal cortex and the anterior cingulated cortex. The power values of the left medial frontal scalp electrode may also be indicative of the neural activity representing Broca’s area. Broca's area is most often association with speech production (a necessary component of the working memory tasks employed in this study) and has many connections with the prefrontal cortex. The left frontal lobe plays a substantial role in language-related planning and movement, such as speech, relative to the right frontal lobe (Kolb & Whishaw, 2003).

Temperament. The associations found among the temperament scales were largely in the hypothesized direction. In general, the scales comprising the Effortful Control factor were positively related with the exception of the non-significant findings including perceptual sensitivity scale. The scales of the Surgency factor were also related in the hypothesized direction; although, the shyness scale was found to be unrelated to activity level and approach with these data. The lack of relation among the scales that comprise the broad temperament factors is not troublesome as each scale was significantly related to the factor upon which it traditionally loads.

The relations among the Surgency and Effortful Control factors and the scales that comprise them were hypothesized to be negatively related, but the relations found were not as consistent as expected. Although those relations that were found to be significant were in the hypothesized direction (with one exception), the associations were fewer than anticipated. Upon further consideration, this finding is in line with the factor structuring of the temperament dimensions as described by Rothbart and colleagues (e.g., Rothbart & Bates, 1998). The paucity of relations among the scales of the Surgency and Effortful Control factors lends support to the existence of separate temperament dimensions and the orthogonality of them. The broad factors of Surgency and Effortful Control were not, in fact, related. Further, the activity level and the inhibitory control scales were the only two temperament scales that were related to both broad factors under investigation, and they were more strongly associated with one factor over the other – hence, their “loading” onto each separate factor.

The inclusion of the impulsivity and anger/frustration scales was valuable as they were both rather strongly and consistently associated with Effortful Control and Surgency factors. More specifically, both scales were negatively related to the Effortful Control factor and the scales that comprise it and were positively related the Surgency factor and the scales that comprise it (with the exception of the logical, negative association found between impulsivity and shyness). These findings with the impulsivity scale are not surprising as impulsive, hasty behaviors are more likely from children who have more surgent and more active behavioral styles and are less likely from those children who have more controlled behavioral styles. Interestingly, the anger scale was related to both Effortful Control and Surgency and specifically suggests that those children who scored higher on the anger/frustration items were rated lower by their parents in Effortful Control and higher by their parents on Surgency. Based on these data and associations, it is unclear whether those children high in Effortful Control are less likely to be or become angry or if they are just better at regulating this emotion. That is, are these high in Effortful Control children able to regulate their behavior because they do not use up their “cognitive space” being angry or do these children use their regulation skills to help them regulate the anger and frustration emotions? From a developmental perspective, it is likely that these children have suffered the same frustrating events in infancy and childhood as all children have, however, it is also likely that these children who are better at regulating their anger emotions have learned how to use their attentional skills, planning, and forethought to combat this anger. These skills have likely been facilitated by consistent and responsive parenting. Wolfe and Bell (2004b) suggest that infants who are highly reactive and fussy around 8-months of age are the same preschool children who do very well on tasks of cognitive control and are more behaviorally reserved.

The nature of association between working memory performance and temperament was different for each of these three age groups. Based on previous research (Wolfe & Bell, 2004a) in which the approach scale of the CBQ was found to be negatively related to working memory performance, negative associations were expected between the working memory tasks and the Surgency factor (and the scales that comprised it – including the approach scale) as well as the impulsivity and anger/frustration scales. Based on conceptual and neurological evidence, positive associations were expected between the working memory tasks and the Effortful Control factor (and the scales that comprised it). There were no formal hypotheses made regarding the age variable save for the strength of these associations was thought to change (either increase or decrease) across these three age groups. Both of the formal hypotheses were supported, but they were not supported concomitantly by the same age group. More specifically, at age 4, positive associations were found between working memory performance and the more regulatory dimensions of temperament (i.e., those associated with Effortful Control), and no negative associations were found between working memory and the Surgency scales (except for one negative association between anger and the simon-says task). Yet at age 4½, a cluster negative associations were found between working memory and the surgent dimensions of temperament (i.e., those associated with the Surgency factor as well as the impulsivity and anger scales), and no positive associations were found with the Effortful Control scales (except for one positive association between the inhibitory control scale and the yes-no task). The associations between the surgent behavioral styles and working memory performance were a replication of previous work in our lab (Wolfe & Bell, 2004a).

At age 3½, there was no discernible pattern of associations between the working memory scales and the temperament dimensions of interest. Other than all Effortful Control scales being negatively related to performance on the DCCS, there were negative and positive associations scattered across all tasks and temperament scales. This pattern (or lack thereof) of temperament-working memory associations was likely due to the previously addressed reduction in sample size and is addressed in the Post-Hoc Analyses section of this document.

It is intriguing that different behavioral styles were associated with working memory performance at these different ages – ages that were separated by only a few months. Specifically, the current study found that 4-year-old children who were high in attention focusing, inhibitory control, low sensitivity pleasure, and Effortful Control in general performed well on the cognitive tasks involving working memory and inhibitory control. For this age group, surgent behavioral styles were not related to cognitive performance. At age 4½, however, Effortful Control and its related scales were not related to cognitive performance, and those children with surgent behavioral styles performed poorly on the working memory tasks.

From a temperament-influences-cognition perspective, perhaps those 4-year-olds whose behavioral styles include high attention focusing, inhibitory control, low sensitivity pleasure, and Effortful Control are at an advantage for cognitive processing, especially when it involves a frontally-associated, attentional control component. Or from a cognition-influences-temperament perspective, perhaps the 4-year-olds included in this dataset are actually ahead of their time with regard to cognitive abilities, and this precociousness facilitates self-regulation.

At age 4½, on the other hand, cognitive functioning that includes working memory, voluntary attention, and inhibitory control should be relatively developed and performance should be relatively high regardless of self-regulatory abilities. A temperament-influences-cognition perspective might suggest, then, that if one has a very surgent, impulsive behavioral style performance on this type of cognitive task will be impaired. A cognition-influences-temperament perspective would purport that some 4½-year-olds are at a disadvantage with regard to cognitive processing and frontal functioning, and this impairs their ability to regulate their surgent and impulsive behaviors.

All of these arguments or propositions are largely based on the construct of attention and question the allocation of cognitive resources for the working memory tasks. These differential working memory-temperament relations seen between the ages of 4 and 4½ should be interpreted and generalized with caution, yet they are intriguing enough to warrant further investigation.

With regard to the explanation of variance in working memory function, the strong association between the approach scale of temperament and working memory performance that was found in previous work with 4½-year-olds was not replicated here. However, the temperament scale with conceptual and neurological similarities to working memory function (i.e., inhibitory control) was found to be associated with performance on the working memory tasks and accounted for 24.9 percent of the variance in this variable. The significant model yielded in the regression procedure included an interaction term between inhibitory control and age. Although the Beta coefficients for the interaction terms did not themselves reach significance, an inspection of the association between the temperament scales and the working memory tasks reveals a negative association between a working memory task and inhibitory control at age 3½ but positive associations at both age 4 and age 4½. These differential associations likely describe the significant model including the interaction terms.

Language. Language receptivity was found to be strongly related to working memory. This was true for the overall group of preschoolers – accounting for over 39 percent of the variance in working memory function – and separately for each age group – with the strength of the relation between language and working memory increasing with age. What is it about knowing a lot of words that is associated with being able to perform these working memory tasks well? Is language ability influencing working memory capacity? Or is working memory capacity allowing for the development of language receptivity? Or is there a third variable influencing both working memory capacity and language receptivity?

All of these explanations are conceivable. First, it is logical that the more words one knows, the better one can think through problems using private-speech or self-talk. Secondly, it is also logical that the more working memory capacity one has the better able to and more quickly he/she will learn words and associate them with their correct meaning. Finally, the third explanation is feasible and can be argued with the inclusion of many different factors. For example, the parents could be influencing both working memory capacity and language receptivity. It is certain that parents are influencing word learning through their behaviors, such as reading and talking to their children and through other experiences that they provide. It is also certain that parents are facilitating the development of working memory capacity and the functioning of the prefrontal cortex through biological (genetic and cellular material) and environmental contributions including the experiences they provide for their children; the way they talk to their children (e.g., Hoff-Ginsberg, 1991); the way they perceive and interact with their children as independent thinkers (e.g., Landry, Smith, Swank, & Miller-Loncar, 2000).

The findings associated with the language expressivity variable were somewhat disappointing. This language measure did not show an increase across the three age groups, nor did it show an association with working memory performance. These null findings are likely due to the language expressivity measure employed in this study – and specifically its location in the study procedure – rather than a characteristic of the construct itself. The language expressivity measure was administered as the very last task during the electrophysiological recording. By this time, the preschool children had been sitting as still as possible for ten minutes or more. They were becoming increasing restless, and their ability to maintain attention to the task at hand was sufficiently taxed. The verbal fluency data were likely influenced by these circumstances.

Multivariate contributions. Once again, the value of considering multiple dimensions of working memory capacity was demonstrated with 41.6 percent of the variance in working memory function explained with the inclusion of age, brain electrical activity from the left medial frontal region, the inhibitory control scale of temperament, and language receptivity. With the inclusion of each new variable, the proportion of variance in working memory function significantly increased suggesting that unique variance was explained by each variable. However, when all of these variables were included together in the final model, the language receptivity variable was the only one that retained a significant Beta coefficient.

Post-hoc Analyses

Throughout the planned statistical analyses, questions arose regarding the 3½ -year-old children's behavioral, physiological, and linguistic data. First, there were questions regarding the relatively high 6-10Hz EEG power values and the stable baseline-to-task activation patterns for the 3½-year-old age group compared to the 4- and 4½ -year-old age groups. Second, there was a series of unsupported age-related hypotheses including working memory, temperament, and linguistic functioning that were very likely the result of the reduction in sample size. The current section addresses these issues by first examining the baseline-to-task EEG power values of those high and low performing children at age 3½. Second, some of the investigations of the age-related differences in working memory, temperament, and linguistic functioning were reanalyzed employing the entire sample of children (including those 3½ -year-old children who *did not contribute* physiological data but *did contribute* working memory, temperament, and linguistic data).

Brain Electrical Activity

To examine the baseline-to-task activation patterns for the high performers at age 3½, the ln EEG (6-10Hz) power values were plotted separately for the low and high working memory (WM) groups for four brain regions (i.e., frontal pole, medial frontal, anterior temporal, and posterior temporal). Low and high WM groups were determined by calculating the mean of the working memory tasks performed during the EEG data collection (i.e., day-night and yes-no) which yielded a WM_2 score. At age 3½, there were four children placed in the high WM group and seven children placed in the low WM group based on natural breaks in the data. See Table 17. Although there were no formal statistical analyses performed on these data, as there were too few children in each group, the graphical representation of the data suggests that those high performing 3½-year-olds have activation patterns more similar to those of the two older age groups (see Figures 5, 6, 7, and 8). Specifically, the graphed data suggest high performing 3½-year-olds have somewhat lower overall power values (similar to the older children) than the low performing children, an increase in EEG power from baseline-to-working memory task, and lower variability for each scalp location.

These findings suggest that those low performing 3½-year-old children have brain organization and function that is different than their preschool-aged counterparts. Perhaps the activation patterns of the low-performing 3½-year olds are reflective of the children’s inability to focus their attention and apply their cognitive resources to the task at hand or perhaps it is that they simple refuse to do so. Either of these hypotheses might explain the undifferentiated baseline and task EEG power values and lower scores on the working memory tasks.

To address this *cannot* or *will-not* issue, a comparison of the parental ratings of the children's attention focusing and inhibitory control abilities for the low and high performing 3½-year-olds was made. The results of two ANOVAs revealed no significant differences between the high and low performance groups at age 3½ on the attention focusing scale or the inhibitory control scale (attention focusing $F = 1.663$, $p > .05$; inhibitory control $F = .003$, $p > .05$). These null findings on both temperament scales suggest that the problem is neither a *cannot* issue (no differences in attention focusing) nor a *will not* issue (no differences in inhibitory control). Also, anecdotally, these children appear to be trying and displaying many of the same behavioral patterns as those children who are experiencing more success on the tasks.

Perhaps the apparent differences between the high and low WM groups at 3½ are not associated with the behavioral styles of the children at all but are simply reflective of individual differences in the functioning of the dorsolateral prefrontal cortex and the associated cognitive processing as described by Engle and colleagues (e.g., Kane & Engle, 2002). This is a likely conclusion as this *is* a self-selected group of children. Only 11 3½-year-olds contributed complete data to these analyses. That is, these are the children that were willing to wear the EEG equipment and that cooperated throughout all tasks. These 11 children do not have significantly higher scores on the attention focusing and inhibitory control scales compared to those 3½ -year-olds who refused the application of the EEG equipment or refused to participate in another task, although the means were in the expected direction (both Fs < 1.885 and both ps > .05). Notably, however, these 11 children did have significantly higher WM_5 scores than those children who self-selected out of the sample (included *M* = 74.03, *SD* = 16.46; not included *M* = 37.55, *SD* = 27.47), *F* (1, 18) = 13.563, *p* = .002.

Age-Related Differences Revisited

Working Memory. The formal, planned analyses demonstrated no significant differences between the different age groups of children with regard to working memory. However, as demonstrated in the final analysis of the last section, 3½-year-old children who self-selected out of the sample had much lower scores on the working memory tasks than those children who remained in the sample. Then, when the entire sample of children (including those children with incomplete data) was included in a regression analysis investigating the value of the age variable in the explanation of variability in working memory function, the results were much different. In this case, support for the hypothesis was found and age was a meaningful variable in the explanation of variability in working memory function, F (2, 58) = 3.927, p = .025, accounting for 12 percent of the variance (R = .345; B_1 = .400; t_1 = 2.801, p_1 = .007; B_2 = .214; t_2 = 1.5, p_2 = .139).

The lack of associations found between the working memory measures at age 3½ in comparison to those found at ages 4 and 4½ was suspicious and likely the result of sample size reduction. Indeed, replicating the Pearson correlation calculations with the full sample of 3½-year-olds yielded positive associations for six of the ten comparisons at this age. Also, two of the four remaining correlations were marginally significant (i.e., $p < .10$) and the last two correlations were in the hypothesized direction. These findings were more in accordance with the study hypotheses and comparable to relations among working memory tasks at both of the older age groups. See Table 18.

Temperament. Previous analyses investigating the relation between the working memory tasks and certain temperament dimensions did not yield a discernible pattern of results for the 3½-year-old age group as was yielded for the two older age groups. When the Pearson analyses were re-accomplished employing the entire sample of 3½-year-olds, a pattern of associations emerged that was similar to that seen at age 4. Specifically, there was a tendency toward a clustering of positive associations between the working memory tasks and the Effortful Control scales of the CBQ. See Table 19.

Linguistic Functioning. In the formal analyses with a small sample size of 3½-year-olds, there were differences between the age groups with regard to language comprehension abilities evinced by performance on the PPVT. Specifically, the PPVT scores of the 3½- and 4-year-old age groups were not significantly different from each other but were significantly different from the scores of the 4½ -year-olds (3½ *M* = 62.09, *SD* = 11.83; 4 *M* = 63.12, *SD* = 10.76; 4½ *M* = 73.06, *SD* = 14.67). These findings were surprising in that the age 3½ and age 4 scores were very similar. Further, these findings only partially supported the hypothesis that the 4½-year-olds would outperform the 4-year-olds who in turn would outperform the 3½-year-olds. Post-hoc analyses including the complete sample of children revealed a different distribution of PPVT scores and also a different pattern of significance among the age groups. Specifically, the results of an ANOVA again revealed a significant difference between the PPVT scores of the three age groups, *F*(2,57) = 4.632, *p* = .014 (3½ *M* = 58.95, *SD* = 12.87; 4 *M* = 62.60, *SD* = 10.68; 4½ *M* = 71.53, *SD* = 14.21) with the significant difference between the 3½ and 4½-year-old PPVT scores (*p* = .014). Although, these findings do not fully support the hypothesis either, the PPVT mean scores for the entire sample of each age group are more reflective of the expected developmental progression for these ages.

Finally, it was hypothesized that since working memory ability and linguistic functioning were both increase with age that perhaps the strength of the relation between these two constructs would increase with age as well. A regression analysis was performed separately for each variable with WM_5 as the dependent variable and the PPVT score as the independent variable. Language receptivity was a valuable associate of working memory at each age group. Further, the t-value increased from age 3½ to age 4 to age 4½ suggesting an increase in strength of association although the standardized Beta coefficients (i.e., the correlation coefficients) at each age did not corroborate this notion.

When this analysis was replicated with the entire sample of children, a similar pattern of results was yielded yet with a more substantial difference among the test values and also now the standardized Beta coefficients (age 3½ $F(1,17) = 5.851$, $p = .027$; age 4 $F(1,19) = 11.321$, $p = .003$; age 4½ $F(1,19) = 25.602$, $p = .000$). See Table 20. Although there were noteworthy differences found between the age groups with regard to the working memory and language associations, follow-up analyses did not reveal any statistically significant differences between them, all z's < 1.96 and all p's > .05. An increase in sample size to reduce the standard error terms would likely facilitate the elucidation of these differences.

General Conclusions

In conclusion, working memory functioning and capacity plays a crucial role in a young child's interaction with the environment and is important for both the cognitive and social domains. Working memory itself is at the seat of many higher-order cognitive, executive, and frontally-associated processes including planning, goal setting, and temporal sequencing, and often has a strong linguistic component. As such, it is a process that is uniquely human and the concept of working memory capacity has been associated with the construct of general fluid intelligence (Kane & Engle, 2002).

Limitations

The generalizability of the findings from this study is bound by a few limitations of the study. First, the homogeneity of the participant population is notable and restricts the generalizability of these findings to similar demographic populations. For example, the large majority of participants are European Caucasian, have older and well educated parents, have attended preschool, and have one or two siblings. It is likely that this advantaged sample was not representative of the general population of children with regard to linguistic functioning and perhaps working memory abilities. It would be interesting to know if similar associations would be found for a different socio-economic status group or for a group of children who had never attended preschool.

Second, the sample size for each age group (n = 20) was chosen in consideration of power and the effect sizes of the constructs of interest in the current study. However, due to incomplete data on one variable or another, the full sample size was not obtained (e.g., psychophysiological measures) and thus not useable in the planned analyses. The formal, planned analyses were greatly affected by this reduction in sample size and subsequent interpretation and generalizability is severely limited. This is especially true for the 3½-year-old age group; some of these concerns were addressed in the Post-Hoc Analyses section.

The third limitation of this study is more a statement of caution in the interpretation of the findings rather than a limitation on generalizability of the findings. Specifically, it is important to remember that these data are cross-sectional and were collected from three different groups of children. Caution must be used when thinking about the *development of* the constructs and the *development of the associations* between the constructs discussed herein. For example, it cannot be claimed that the associations between temperament and working memory *change* across the early childhood years, although these data coupled with previous research certainly suggest this notion. The best way to address the issue of change and developmental process is to include the same children at the different ages. It would be interesting to know how these data and associations might look different if the sample was a longitudinal one.

Future Directions

The future directions for research in this area should include a consideration of the aforementioned limitations of the current study. Specifically, in future work, efforts should be made to increase the diversity of the sample in terms of ethnicity, socio-economic status, and early childhood experiences, to increase the sample size, and to formulate and employ an applicable longitudinal design. With regard to conceptual and theoretical pursuits, future work should continue the investigation of the relation between cognition and the regulatory dimensions of temperament with a special consideration of the age. Future work should also concentrate on other psychophysiological processes (i.e., cardiac and autonomic processes) that are associated with both cognitive and emotional control including heart rate and heart rate variability. In the future, research should include the investigation of parental contributions to the variability in working memory function – perhaps a mediating process via parent influences on emotion regulation or on linguistic development.

Finally, future work in this area should thoroughly examine this robust relation between working memory and language receptivity and investigate what features of language or working memory ability might be influencing the strong (and increasing) association between them. Given the importance of working memory capacity and function, if there was someway to increase it (e.g., through the facilitation of word learning), then this would be invaluable to know and the implications of having this information are extraordinary for the scientific community, the structure of the elementary school curriculum, and for the parents wanting to optimize the cognitive and social development of their children.

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Footnotes

[1] The final goal of this section requires a multiple regression procedure that includes brain electrical activity, temperament, and language in the explanation of variance in working memory performance. The specific variables included in the final analysis will be determined by the preceding results of each individual regression analysis for EEG, temperament, and language. In order for the sample to be consistent across each individual regression analysis as well as in the final multiple regression procedure, only those children with complete data can be used for the analyses in this section of the results. This necessary criterion reduced the sample size to 46 children. At age 3½, nine of the 20 children refused to wear the EEG cap resulting in complete data for 11 3½-year-olds (the same as for previous analyses). At age 4, two of the 20 children refused to wear the EEG cap, and one did not contribute temperament data resulting in complete data for 17 4-year-olds. At age 4½, two of the 21 children refused to wear the EEG cap, and one did not contribute temperament data resulting in complete data for 18 4½-year-olds. The implications of this reduction are addressed in the Discussion section.

[2] *TT*: tongue task; *SS*: Simon-says task; *DN*: day-night task; *YN*: yes-no task; *VF*: verbal fluency task; *DCCS*: dimensional change card sort task; *WM5*: working memory composite score; *PPVT*: Peabody Picture Vocabulary Test; *cbqAL*: activity level; *cbqAN*: anger/frustration; *cbqAP*: approach/anticipation; *cbqAF*: attention focusing; *cbqAS*: attention shifting; *cbqDS: discomfort; cbqSO*: soothability; *cbqFE*: fear; *cbqHP*: high pleasure; *cbqIM*: impulsivity; *cbqIC*: inhibitory control; *cbqLP*: low pleasure; *cbqSE*: sensitivity; *cbqSD*: sadness; *cbqSH*: shyness; *cbqSM*: smiling and laughter; *cbqSURG*: surgency factor; *cbqNEG*: negative affect factor; *cbqEEFC*: effortful control factor; *eegf1*: left frontal pole; *eegf2*: right frontal pole; *eegf3*: left medial frontal; *eegf4*: right medial frontal; *eegf7*: left lateral frontal; *eegf8* right lateral frontal;

eegc3: left central; *eegc4*: right central; *eegt3*: left anterior temporal; *eegt4*: right anterior temporal; *eegt5*: left posterior temporal; *eegt6*: right posterior temporal; *eegp3*: left parietal; *eegp4*: right parietal; *eego1*: left occipital; *eego2*: right occipital.

Table 1: *Demographic Information*

Percent of participants who were male	49.2
Percent of participants with 1 or 2 siblings	80.4
Percent of participants who were European Caucasian	85.24
Percent of right-handed parents	84.48
Mean age of mother (in years)	33.46
Mean age of father (in years)	35.64
Mean education level of mother (in years)	16.20
Mean education level of father (in years)	16.32
Percent of participants who attended preschool	90.2

Table 2: *Summary of Multivariate Analyses F Values for Comparisons by Region*

	df	*Fp1/Fp2*	*F3/F4*	*F7/F8*	*C3/C4*	*T3/T4*	*T5/T6*	*P3/P4*	*O1/O2*
Condition	*1,44*	16.23	9.71				19.522		
Condition x Age	*2,44*								
Hemisphere	*1,44*								
Hemisphere x Age	*2,44*					5.67			
Condition x Hemisphere	*1,44*	9.63							
Condition x Hemisphere x Age	*2,44*								

Note: Only those values significant at $p \leq .006$ are shown.

Table 3: *Summary of Multivariate Analyses F Values for Age Comparisons by Region*

	df	*Fp1/Fp2*	*F3/F4*	*T3/T4*	*T5/T6*
AGE 3½					
Condition	*1,10*				
Hemisphere	*1,10*				
Condition x Hemisphere	*1,10*				
AGE 4					
Condition	*1,16*	13.85	12.25	20.48	21.65
Hemisphere	*1,16*				
Condition x Hemisphere	*1,16*				
AGE 4½					
Condition	*1,18*		12.06		10.82
Hemisphere	*1,18*				
Condition x Hemisphere	*1,18*				

Note: Only those values significant at $p \leq .004$ are shown.

Table 4: *Pearson Correlations between all Variables for Age 3½*

agegroup		TT	SS	DN	YN	VF	DCCS	WM5	PPVT
3.5-years	TT	1.000							
(n = 11)	SS	-.071	1.000						
	DN	-.057	-.519	1.000					
	YN	.304	-.152	.179	1.000				
	VF	.416	.000	.209	.531	1.000			
	DCCS	.384	.275	-.111	.440	.346	1.000		
	WM5	.519	.421	-.023	.640	.527	.866	1.000	
	PPVT	.421	.294	.088	.443	.543	.351	.611	1.000
	cbqAL	.317	-.006	.255	-.051	-.004	.607	.419	.078
	cbqAN	.230	.055	-.007	-.330	.273	.374	.146	.141
	cbqAP	.046	-.332	.288	-.335	-.196	.051	-.182	.116
	cbqAF	-.332	.444	-.095	-.245	-.141	-.531	-.250	.125
	cbqAS	-.249	-.154	.085	.151	-.261	-.467	-.293	-.320
	cbqDS	.351	-.316	.435	.268	.481	.377	.327	.067
	cbqSO	-.299	-.246	.455	.185	-.361	-.231	-.137	.253
	cbqFE	.178	-.173	-.196	.361	.002	.477	.290	-.033
	cbqHP	-.587	-.032	.006	-.408	-.593	-.420	-.529	-.591
	cbqIM	.281	-.170	.001	-.118	-.034	.110	.002	.139
	cbqIC	-.504	.113	.424	-.097	-.264	-.497	-.263	-.003
	cbqLP	-.314	.131	.036	-.142	-.243	-.556	-.339	-.186
	cbqSE	-.130	.133	.166	-.366	-.205	-.273	-.204	-.255
	cbqSD	.543	.123	-.203	-.048	.435	.609	.438	.200
	cbqSH	.157	.035	-.264	.141	-.018	.361	.229	-.214
	cbqSM	-.223	-.229	.396	-.042	-.378	-.541	-.360	-.009
	cbqSURG	-.116	-.133	.292	-.315	-.253	-.025	-.158	-.047
	cbqNEG	.407	-.016	-.083	-.016	.407	.525	.333	.046
	cbqEFFC	-.444	.295	.197	-.293	-.284	-.621	-.346	-.080
	eegf1	.293	.309	-.455	.154	.122	.100	.228	.501
	eegf2	.384	.162	-.413	.139	.238	.208	.239	.411
	eegf3	.297	.137	-.197	.262	.388	.283	.336	.631
	eegf4	.260	-.118	-.169	.246	.339	.159	.144	.431
	eegf7	.502	.148	-.547	.144	.282	.260	.260	.403
	eegf8	.419	.000	-.286	.238	.345	.292	.278	.500
	eegc3	.164	.237	-.297	-.159	.294	.121	.089	.582
	eegc4	.010	-.115	-.154	-.007	.136	.030	-.076	.409
	eegt3	.415	-.037	-.209	.071	.150	.305	.220	.504
	eegt4	.364	-.201	-.109	.008	.209	.158	.055	.428
	eegt5	.443	-.301	-.027	.134	.162	-.191	-.078	.262
	eegt6	.099	-.413	.075	-.043	-.018	-.386	-.361	.083
	eegp3	.260	.194	-.254	.096	.324	.189	.233	.487
	eegp4	.248	.104	-.440	.032	.283	.134	.093	.443
	eego1	.455	.339	-.239	.332	.281	.233	.467	.668
	eego2	.634	.014	.012	.328	.483	.485	.538	.583

Note: Correlations ≥ .519 are significant at .05 level; one-tailed tests of significance[2]

Table 4, continued: *Pearson Correlations between all Variables for Age 3½*

agegroup		cbqAL	cbqAN	cbqAP	cbqAF	cbqAS	cbqDS	cbqSO	cbqFE	cbqHP
3.5-years (n = 11)	TT									
	SS									
	DN									
	YN									
	VF									
	DCCS									
	WM5									
	PPVT									
	cbqAL	1.000								
	cbqAN	.658	1.000							
	cbqAP	.620	.585	1.000						
	cbqAF	-.502	-.193	-.362	1.000					
	cbqAS	-.676	-.901	-.513	.161	1.000				
	cbqDS	.684	.615	.313	-.368	-.624	1.000			
	cbqSO	-.163	-.498	.159	.196	.332	-.332	1.000		
	cbqFE	.426	.377	.160	-.248	-.493	.528	-.159	1.000	
	cbqHP	.124	-.076	.285	.052	.123	-.025	.004	-.018	1.000
	cbqIM	.587	.523	.807	-.401	-.479	.406	-.192	.293	.378
	cbqIC	-.462	-.617	-.301	.595	.614	-.506	.659	-.634	.106
	cbqLP	-.756	-.697	-.631	.626	.763	-.690	.342	-.596	-.106
	cbqSE	.047	-.268	-.028	-.110	.257	-.164	.000	-.706	.392
	cbqSD	.608	.804	.394	-.490	-.666	.515	-.706	.335	-.227
	cbqSH	-.034	-.083	-.525	-.120	-.055	.013	-.118	.298	-.468
	cbqSM	-.116	-.534	.177	.094	.388	-.209	.638	-.445	.460
	cbqSURG	.637	.447	.851	-.246	-.363	.350	.034	.097	.646
	cbqNEG	.675	.884	.369	-.377	-.807	.784	-.690	.596	-.091
	cbqEFFC	-.526	-.563	-.406	.727	.559	-.550	.412	-.722	.177
	eegf1	-.359	-.010	-.316	.460	-.133	-.312	.104	.201	-.674
	eegf2	-.125	.279	-.198	.291	-.435	.046	-.100	.442	-.660
	eegf3	-.124	.267	-.110	.258	-.435	.040	.104	.325	-.766
	eegf4	-.206	.224	-.114	.165	-.361	.072	.092	.386	-.725
	eegf7	-.111	.324	-.137	.131	-.433	.029	-.260	.454	-.652
	eegf8	-.045	.345	-.044	.103	-.503	.146	-.033	.476	-.721
	eegc3	-.124	.465	.163	.263	-.513	-.130	-.028	.042	-.586
	eegc4	-.263	.225	.124	.176	-.294	-.192	.266	.172	-.584
	eegt3	.026	.328	.152	.013	-.423	-.040	.148	.314	-.744
	eegt4	-.007	.417	.232	.031	-.456	.066	.098	.319	-.682
	eegt5	-.392	-.090	-.210	.252	.066	-.124	.191	.071	-.705
	eegt6	-.431	-.037	-.060	.380	.068	-.146	.308	.110	-.458
	eegp3	-.172	.310	-.183	.386	-.411	.005	-.017	.289	-.728
	eegp4	-.177	.415	.029	.239	-.480	-.015	-.144	.386	-.563
	eego1	-.251	-.080	-.368	.397	-.082	-.212	.178	.090	-.805
	eego2	.199	.393	-.039	.011	-.487	.334	-.039	.389	-.859

Note: Correlations $\geq$ .519 are significant at .05 level; one-tailed tests of significance[2]

Table 4, continued: *Pearson Correlations between all Variables for Age 3½*

agegroup		cbqIM	cbqIC	cbqLP	cbqSE	cbqSD	cbqSH	cbqSL	cbqSURG	cbqNEG
3.5- years (n = 11)	TT									
	SS									
	DN									
	YN									
	VF									
	DCCS									
	WM5									
	PPVT									
	cbqAL									
	cbqAN									
	cbqAP									
	cbqAF									
	cbqAS									
	cbqDS									
	cbqSO									
	cbqFE									
	cbqHP									
	cbqIM	1.000								
	cbqIC	-.582	1.000							
	cbqLP	-.785	.814	1.000						
	cbqSE	-.029	.333	.186	1.000					
	cbqSD	.574	-.811	-.737	-.224	1.000				
	cbqSH	-.629	-.134	.164	-.144	-.072	1.000			
	cbqSM	.114	.537	.220	.612	-.644	-.405	1.000		
	cbqSURG	.847	-.189	-.590	.193	.313	-.713	.316	1.000	
	cbqNEG	.526	-.822	-.798	-.336	.879	.050	-.630	.329	1.000
	cbqEFFC	-.567	.922	.848	.476	-.751	-.116	.511	-.231	-.762
	eegf1	-.337	-.026	.251	-.600	-.040	.382	-.387	-.606	-.078
	eegf2	-.204	-.309	-.036	-.655	.170	.503	-.520	-.519	.263
	eegf3	-.235	-.163	-.039	-.660	.129	.385	-.449	-.481	.175
	eegf4	-.263	-.219	-.023	-.694	.065	.466	-.441	-.531	.169
	eegf7	-.039	-.502	-.158	-.662	.350	.415	-.595	-.458	.356
	eegf8	-.100	-.388	-.185	-.693	.245	.446	-.499	-.437	.321
	eegc3	-.014	-.187	-.087	-.469	.293	.077	-.431	-.218	.205
	eegc4	-.184	-.069	.039	-.612	.004	.238	-.328	-.344	-.001
	eegt3	-.064	-.272	-.114	-.611	.240	.385	-.425	-.332	.188
	eegt4	-.003	-.299	-.144	-.650	.255	.290	-.427	-.263	.262
	eegt5	-.341	.033	.343	-.471	-.147	.383	-.181	-.595	-.128
	eegt6	-.317	.156	.380	-.551	-.281	.245	-.135	-.429	-.167
	eegp3	-.311	-.131	.074	-.659	.136	.428	-.549	-.526	.202
	eegp4	.003	-.390	-.153	-.736	.301	.210	-.570	-.324	.321
	eego1	-.381	.081	.271	-.473	-.033	.373	-.296	-.621	-.114
	eego2	-.127	-.299	-.174	-.588	.365	.455	-.523	-.391	.398

Note: Correlations $\geq$ .519 are significant at .05 level; one-tailed tests of significance[2]

Table 4, continued: *Pearson Correlations between all Variables for Age 3½*

agegroup		cbqEFFC	eegf1	eegf2	eegf3	eegf4	eegf7	eegf8	eegc3	eegc4
3.5-years (n = 11)	TT									
	SS									
	DN									
	YN									
	VF									
	DCCS									
	WM5									
	PPVT									
	cbqAL									
	cbqAN									
	cbqAP									
	cbqAF									
	cbqAS									
	cbqDS									
	cbqSO									
	cbqFE									
	cbqHP									
	cbqIM									
	cbqIC									
	cbqLP									
	cbqSE									
	cbqSD									
	cbqSH									
	cbqSM									
	cbqSURG									
	cbqNEG									
	cbqEFFC	1.000								
	eegf1	.017	1.000							
	eegf2	-.243	.908	1.000						
	eegf3	-.200	.879	.925	1.000					
	eegf4	-.268	.817	.915	.952	1.000				
	eegf7	-.412	.865	.956	.855	.852	1.000			
	eegf8	-.393	.838	.962	.957	.965	.936	1.000		
	eegc3	-.152	.738	.749	.843	.769	.747	.789	1.000	
	eegc4	-.162	.733	.736	.852	.887	.689	.817	.871	1.000
	eegt3	-.339	.805	.844	.889	.880	.830	.908	.824	.878
	eegt4	-.363	.728	.821	.864	.904	.807	.903	.837	.910
	eegt5	.022	.748	.734	.695	.789	.686	.729	.515	.672
	eegt6	.101	.639	.633	.615	.750	.542	.631	.502	.739
	eegp3	-.112	.900	.950	.965	.927	.871	.928	.842	.821
	eegp4	-.349	.831	.903	.889	.885	.924	.918	.892	.852
	eego1	.083	.929	.811	.843	.728	.748	.760	.628	.589
	eego2	-.356	.708	.827	.864	.817	.780	.872	.635	.609

Note: Correlations ≥ .519 are significant at .05 level; one-tailed tests of significance[2]

Table 4, continued: *Pearson Correlations between all Variables for Age 3½*

agegroup		eegt3	eegt4	eegt5	eegt6	eegp3	eegp4	eego1	eego2
3.5-years (n = 11)	TT								
	SS								
	DN								
	YN								
	VF								
	DCCS								
	WM5								
	PPVT								
	cbqAL								
	cbqAN								
	cbqAP								
	cbqAF								
	cbqAS								
	cbqDS								
	cbqSO								
	cbqFE								
	cbqHP								
	cbqIM								
	cbqIC								
	cbqLP								
	cbqSE								
	cbqSD								
	cbqSH								
	cbqSM								
	cbqSURG								
	cbqNEG								
	cbqEFFC								
	eegf1								
	eegf2								
	eegf3								
	eegf4								
	eegf7								
	eegf8								
	eegc3								
	eegc4								
	eegt3	1.000							
	eegt4	.963	1.000						
	eegt5	.739	.773	1.000					
	eegt6	.656	.755	.908	1.000				
	eegp3	.856	.849	.727	.676	1.000			
	eegp4	.840	.872	.631	.618	.901	1.000		
	eego1	.745	.632	.722	.521	.830	.660	1.000	
	eego2	.842	.808	.693	.515	.843	.698	.790	1.000

Note: Correlations ≥ .519 are significant at .05 level; one-tailed tests of significance[2]

Table 5: *Pearson Correlations between all Variables for Age 4*

agegroup		TT	SS	DN	YN	VF	DCCS	WM5	PPVT
4-years	TT	1.000							
(n = 17)	SS	.202	1.000						
	DN	-.018	.334	1.000					
	YN	.345	.700	.538	1.000				
	VF	.225	.336	.525	.157	1.000			
	DCCS	.286	.432	.582	.395	.403	1.000		
	WM5	.494	.794	.647	.844	.444	.757	1.000	
	PPVT	.325	.614	.166	.261	.327	.505	.553	1.000
	cbqAL	-.173	-.073	-.117	-.082	-.127	-.235	-.186	-.274
	cbqAN	-.308	-.343	-.094	-.141	-.200	.011	-.247	-.347
	cbqAP	-.031	-.285	-.054	.164	-.323	-.260	-.147	-.464
	cbqAF	-.054	.627	.184	.291	.108	.161	.372	.558
	cbqAS	-.017	.342	-.025	.285	-.069	-.073	.168	.172
	cbqDS	-.029	-.679	-.285	-.278	-.264	-.278	-.463	-.358
	cbqSO	.053	.432	-.119	-.020	.063	-.226	.060	.392
	cbqFE	-.129	-.547	.047	-.092	-.117	-.035	-.245	-.452
	cbqHP	.031	-.104	.091	-.003	-.137	.165	.041	-.276
	cbqIM	.333	-.216	-.278	-.028	-.158	-.316	-.155	-.161
	cbqIC	.289	.421	.244	.329	.157	.464	.502	.542
	cbqLP	.114	.405	.273	.237	.143	.340	.395	.214
	cbqSE	.125	-.154	-.121	.074	-.043	.241	.050	.240
	cbqSD	.065	-.271	.035	.152	.002	-.055	-.042	-.216
	cbqSH	-.636	-.292	-.038	-.207	-.162	-.300	-.413	-.486
	cbqSM	.129	-.153	-.070	.247	-.253	-.147	-.008	-.467
	cbqSURG	.230	-.011	-.002	.106	-.113	.052	.098	-.113
	cbqNEG	-.096	-.536	-.031	-.066	-.143	-.028	-.240	-.417
	cbqEFFC	.145	.513	.222	.336	.136	.400	.476	.565
	eegf1	-.201	.342	.202	.302	.126	.011	.202	.108
	eegf2	-.143	.241	.148	.226	.129	-.109	.110	.093
	eegf3	.180	.300	.304	.418	.511	.036	.340	.020
	eegf4	.110	.497	.403	.588	.452	.173	.502	.202
	eegf7	.232	.277	.124	.363	.258	-.217	.214	.058
	eegf8	-.062	.459	.182	.421	.250	-.065	.281	.152
	eegc3	-.065	.144	.287	.224	.114	.146	.194	.016
	eegc4	.132	.301	.241	.423	.205	.052	.310	.215
	eegt3	.226	.250	.236	.376	.460	.135	.339	.294
	eegt4	.172	.295	.274	.430	.228	.116	.358	.289
	eegt5	.039	.115	-.184	.075	.229	.009	.037	.324
	eegt6	.115	.271	.112	.168	.386	.229	.262	.561
	eegp3	.108	.309	.510	.498	.434	.332	.482	.119
	eegp4	-.420	.341	.185	.111	.245	.156	.133	.205
	eego1	-.044	.083	.192	.113	.220	.233	.161	.163
	eego2	-.384	.388	.026	.157	-.096	-.036	.080	.278

Note: Correlations ≥ .413 are significant at .05 level; one-tailed tests of significance[2]

Table 5, continued: *Pearson Correlations between all Variables for Age 4*

agegroup		cbqAL	cbqAN	cbqAP	cbqAF	cbqAS	cbqDS	cbqSO	cbqFE	cbqHP
4-years	TT									
(n = 17)	SS									
	DN									
	YN									
	VF									
	DCCS									
	WM5									
	PPVT									
	cbqAL	1.000								
	cbqAN	.574	1.000							
	cbqAP	.560	.534	1.000						
	cbqAF	-.447	-.495	-.398	1.000					
	cbqAS	-.767	-.561	-.394	.619	1.000				
	cbqDS	-.069	.511	.404	-.461	-.021	1.000			
	cbqSO	-.209	-.815	-.510	.537	.444	-.593	1.000		
	cbqFE	.120	.665	.345	-.547	-.229	.611	-.740	1.000	
	cbqHP	.579	.174	.448	-.390	-.656	-.255	-.207	-.143	1.000
	cbqIM	.481	.086	.522	-.531	-.497	.119	-.116	-.019	.521
	cbqIC	-.734	-.594	-.383	.603	.590	-.291	.318	-.270	-.263
	cbqLP	-.482	-.496	-.160	.649	.401	-.488	.244	-.425	.032
	cbqSE	-.273	.181	.230	-.205	.037	.424	-.384	.299	-.177
	cbqSD	.253	.579	.713	-.324	-.180	.687	-.618	.511	.007
	cbqSH	-.022	.192	.088	.128	.203	.125	-.101	.325	-.175
	cbqSM	-.028	.103	.511	-.297	-.004	.191	-.421	.150	.241
	cbqSURG	.756	.331	.608	-.485	-.742	-.081	-.248	-.073	.818
	cbqNEG	.250	.837	.602	-.558	-.332	.809	-.893	.841	-.006
	cbqEFFC	-.674	-.536	-.303	.805	.616	-.351	.329	-.394	-.300
	eegf1	.461	.024	.391	.124	-.273	-.395	.070	-.267	.469
	eegf2	.531	.005	.339	.027	-.390	-.407	.122	-.227	.495
	eegf3	.198	-.186	.237	-.061	-.110	-.253	.075	-.130	.235
	eegf4	.203	-.112	.289	.124	-.049	-.317	.080	-.162	.210
	eegf7	.264	-.242	.342	.171	-.027	-.241	.272	-.177	.088
	eegf8	.521	.051	.242	.110	-.282	-.433	.123	-.242	.309
	eegc3	.368	.210	.255	-.073	-.399	-.199	-.106	.110	.297
	eegc4	.427	-.021	.316	-.108	-.337	-.277	.092	.004	.329
	eegt3	.226	.048	.160	-.136	-.197	-.044	-.075	.152	.036
	eegt4	.239	-.104	.253	-.038	-.124	-.157	.149	-.025	.131
	eegt5	.217	.179	.153	-.175	-.060	.201	-.027	.188	-.139
	eegt6	.101	.061	.061	.141	-.054	.057	.033	.032	-.095
	eegp3	.465	.284	.371	-.134	-.321	-.062	-.219	.211	.262
	eegp4	.505	.260	-.007	.006	-.381	-.367	.021	-.185	.288
	eego1	-.059	-.099	.019	-.007	-.055	-.107	.019	-.012	.153
	eego2	-.051	-.207	-.100	.462	.314	-.316	.409	-.296	-.063

Note: Correlations $\geq$ .413 are significant at .05 level; one-tailed tests of significance[2]

Table 5, continued: *Pearson Correlations between all Variables for Age 4*

agegroup		cbqIM	cbqIC	cbqLP	cbqSE	cbqSD	cbqSH	cbqSL	cbqSURG	cbqNEG
4-years	TT									
(n = 17)	SS									
	DN									
	YN									
	VF									
	DCCS									
	WM5									
	PPVT									
	cbqAL									
	cbqAN									
	cbqAP									
	cbqAF									
	cbqAS									
	cbqDS									
	cbqSO									
	cbqFE									
	cbqHP									
	cbqIM	1.000								
	cbqIC	-.219	1.000							
	cbqLP	-.230	.718	1.000						
	cbqSE	.119	.279	-.032	1.000					
	cbqSD	.134	-.368	-.338	.390	1.000				
	cbqSH	-.569	-.220	-.032	-.130	.142	1.000			
	cbqSM	.472	.020	.274	.310	.185	-.144	1.000		
	cbqSURG	.782	-.374	-.189	-.053	.216	-.510	.288	1.000	
	cbqNEG	.103	-.430	-.466	.405	.820	.212	.253	.149	1.000
	cbqEFFC	-.354	.911	.841	.249	-.279	-.063	.038	-.418	-.441
	eegf1	.422	.088	.182	.025	-.074	-.068	.198	.495	-.186
	eegf2	.508	-.026	-.002	-.082	-.128	-.085	.063	.526	-.209
	eegf3	.405	.147	.082	.069	.024	-.128	.227	.288	-.138
	eegf4	.288	.252	.150	.131	.086	-.132	.122	.295	-.129
	eegf7	.370	.137	.134	-.069	.055	-.019	.114	.230	-.197
	eegf8	.339	-.108	-.088	-.160	-.060	-.059	-.015	.405	-.193
	eegc3	.236	.126	-.073	-.034	-.175	-.016	-.056	.326	.006
	eegc4	.473	.081	-.218	.099	.071	-.167	-.052	.445	-.075
	eegt3	.413	.147	-.224	.276	.161	-.270	-.020	.260	.101
	eegt4	.384	.243	-.116	.246	.043	-.238	-.045	.314	-.086
	eegt5	.211	-.025	-.432	.498	.394	-.065	-.235	.091	.242
	eegt6	.185	.296	-.130	.334	.236	-.230	-.347	.117	.089
	eegp3	.165	-.075	-.222	.020	.393	-.061	-.157	.400	.257
	eegp4	.034	-.217	-.255	-.068	-.160	.061	-.287	.272	-.125
	eego1	.195	.445	.103	.306	-.223	-.066	.011	.077	-.112
	eego2	-.047	.451	.206	-.008	-.384	.100	-.194	-.116	-.390

Note: Correlations ≥ .413 are significant at .05 level; one-tailed tests of significance[2]

Table 5, continued: *Pearson Correlations between all Variables for Age 4*

agegroup		cbqEFFC	eegf1	eegf2	eegf3	eegf4	eegf7	eegf8	eegc3	eegc4
4-years (n = 17)	TT									
	SS									
	DN									
	YN									
	VF									
	DCCS									
	WM5									
	PPVT									
	cbqAL									
	cbqAN									
	cbqAP									
	cbqAF									
	cbqAS									
	cbqDS									
	cbqSO									
	cbqFE									
	cbqHP									
	cbqIM									
	cbqIC									
	cbqLP									
	cbqSE									
	cbqSD									
	cbqSH									
	cbqSM									
	cbqSURG									
	cbqNEG									
	cbqEFFC	1.000								
	eegf1	.148	1.000							
	eegf2	-.018	.927	1.000						
	eegf3	.067	.838	.811	1.000					
	eegf4	.223	.853	.819	.915	1.000				
	eegf7	.148	.698	.684	.826	.775	1.000			
	eegf8	-.057	.843	.922	.734	.816	.681	1.000		
	eegc3	-.019	.739	.762	.618	.679	.581	.668	1.000	
	eegc4	-.060	.775	.852	.781	.823	.730	.813	.716	1.000
	eegt3	-.009	.635	.679	.809	.799	.655	.673	.619	.879
	eegt4	.094	.700	.702	.782	.834	.756	.654	.758	.902
	eegt5	-.094	.294	.286	.406	.441	.323	.329	.183	.575
	eegt6	.210	.472	.460	.499	.605	.457	.446	.456	.675
	eegp3	-.149	.565	.538	.672	.746	.569	.609	.657	.786
	eegp4	-.169	.686	.711	.448	.550	.242	.773	.611	.574
	eego1	.262	.674	.639	.672	.678	.481	.460	.817	.643
	eego2	.426	.618	.573	.355	.526	.374	.502	.756	.592

Note: Correlations ≥ .413 are significant at .05 level; one-tailed tests of significance[2]

Table 5, continued: *Pearson Correlations between all Variables for Age 4*

agegroup		eegt3	eegt4	eegt5	eegt6	eegp3	eegp4	eego1	eego2
4-years	TT								
(n = 17)	SS								
	DN								
	YN								
	VF								
	DCCS								
	WM5								
	PPVT								
	cbqAL								
	cbqAN								
	cbqAP								
	cbqAF								
	cbqAS								
	cbqDS								
	cbqSO								
	cbqFE								
	cbqHP								
	cbqIM								
	cbqIC								
	cbqLP								
	cbqSE								
	cbqSD								
	cbqSH								
	cbqSM								
	cbqSURG								
	cbqNEG								
	cbqEFFC								
	eegf1								
	eegf2								
	eegf3								
	eegf4								
	eegf7								
	eegf8								
	eegc3								
	eegc4								
	eegt3	1.000							
	eegt4	.855	1.000						
	eegt5	.714	.581	1.000					
	eegt6	.811	.708	.807	1.000				
	eegp3	.762	.743	.538	.653	1.000			
	eegp4	.483	.471	.366	.417	.516	1.000		
	eego1	.659	.756	.353	.582	.451	.491	1.000	
	eego2	.354	.546	.247	.480	.210	.526	.685	1.000

Note: Correlations ≥ .413 are significant at .05 level; one-tailed tests of significance[2]

Table 6: *Pearson Correlations between all Variables for Age 4½*

agegroup		TT	SS	DN	YN	VF	DCCS	WM5	PPVT
4.5-years	TT	1.000							
(n = 18)	SS	.822	1.000						
	DN	.773	.836	1.000					
	YN	.414	.470	.352	1.000				
	VF	.276	.367	.462	-.111	1.000			
	DCCS	.754	.944	.858	.429	.326	1.000		
	WM5	.823	.907	.838	.749	.235	.893	1.000	
	PPVT	.671	.613	.688	.377	.354	.714	.699	1.000
	cbqAL	-.347	-.199	-.415	.199	-.006	-.205	-.144	-.329
	cbqAN	-.234	-.149	-.355	.071	-.171	-.069	-.121	-.040
	cbqAP	-.323	-.170	-.124	.309	.001	-.132	-.008	-.049
	cbqAF	-.330	-.125	-.071	-.084	.074	.025	-.113	.257
	cbqAS	-.001	-.065	.043	-.005	-.110	-.095	-.029	-.152
	cbqDS	.239	.288	.254	-.142	.295	.351	.170	.355
	cbqSO	.151	-.024	.052	.120	-.241	-.104	.054	-.024
	cbqFE	.138	.154	.098	-.021	-.192	.160	.100	.231
	cbqHP	-.415	-.384	-.522	.042	-.094	-.381	-.318	-.462
	cbqIM	-.397	-.345	-.451	-.013	-.271	-.343	-.308	-.591
	cbqIC	.176	.111	.231	.454	-.027	.105	.315	.262
	cbqLP	-.052	.005	.046	.084	.047	.019	.043	.344
	cbqSE	-.413	-.240	-.204	-.122	.070	-.252	-.266	-.139
	cbqSD	.097	.134	.069	.257	-.191	.121	.191	.031
	cbqSH	.400	.220	.300	-.164	.263	.198	.144	.476
	cbqSM	-.198	-.178	-.182	.089	.024	-.124	-.091	.251
	cbqSURG	-.459	-.310	-.434	.199	-.125	-.294	-.206	-.431
	cbqNEG	.010	.102	-.012	.010	-.021	.156	.061	.144
	cbqEFFC	-.302	-.132	-.034	.094	.072	-.071	-.055	.248
	eegf1	.015	-.051	.137	-.098	.299	-.062	-.035	.046
	eegf2	.226	.178	.296	-.165	.391	.140	.092	.294
	eegf3	.240	.193	.312	.083	.343	.246	.236	.435
	eegf4	.319	.199	.267	-.057	.333	.207	.169	.392
	eegf7	.236	.197	.411	-.155	.510	.208	.144	.219
	eegf8	.246	.199	.287	-.168	.466	.145	.096	.158
	eegc3	.180	.188	.180	.130	.241	.266	.224	.198
	eegc4	.178	.138	.209	.088	.218	.145	.170	.094
	eegt3	.308	.242	.385	.150	.147	.277	.306	.403
	eegt4	.364	.272	.361	.160	.268	.250	.310	.402
	eegt5	.322	.248	.373	.252	.254	.285	.352	.420
	eegt6	.272	.279	.341	.175	.338	.293	.310	.365
	eegp3	.383	.348	.360	-.110	.574	.318	.227	.379
	eegp4	.207	.258	.272	-.238	.581	.197	.079	.211
	eego1	.146	.251	.142	.022	.382	.191	.149	.221
	eego2	.136	.110	.168	-.034	.298	.042	.069	.193

Note: Correlations $\geq$ .400 are significant at .05 level; one-tailed tests of significance[2]

Table 6, continued: *Pearson Correlations between all Variables for Age 4½*

agegroup		cbqAL	cbqAN	cbqAP	cbqAF	cbqAS	cbqDS	cbqSO	cbqFE	cbqHP
4.5-years (n = 18)	TT									
	SS									
	DN									
	YN									
	VF									
	DCCS									
	WM5									
	PPVT									
	cbqAL	1.000								
	cbqAN	.535	1.000							
	cbqAP	.627	.554	1.000						
	cbqAF	.211	.368	.411	1.000					
	cbqAS	-.251	-.805	-.538	-.431	1.000				
	cbqDS	-.240	.455	-.029	.109	-.609	1.000			
	cbqSO	-.359	-.764	-.462	-.391	.815	-.713	1.000		
	cbqFE	-.195	.488	.214	.164	-.637	.672	-.509	1.000	
	cbqHP	.813	.397	.372	.180	-.175	-.423	-.169	-.437	1.000
	cbqIM	.639	.284	.263	.100	-.023	-.504	-.037	-.355	.795
	cbqIC	-.124	-.542	-.144	-.086	.623	-.482	.681	-.544	-.078
	cbqLP	.126	.182	.341	.344	-.184	.128	-.113	.234	-.045
	cbqSE	.295	.040	.517	.440	-.049	-.220	-.120	.037	.012
	cbqSD	.324	.524	.638	.119	-.527	.246	-.499	.522	.018
	cbqSH	-.572	-.062	-.179	-.128	-.175	.567	-.093	.427	-.735
	cbqSM	.275	-.182	.069	.344	.359	-.459	.352	-.345	.200
	cbqSURG	.909	.443	.606	.265	-.202	-.419	-.237	-.306	.923
	cbqNEG	.202	.821	.468	.297	-.858	.767	-.873	.812	-.061
	cbqEFFC	.235	.044	.495	.731	-.047	-.193	-.021	-.029	.040
	eegf1	-.307	-.270	-.084	-.073	.167	.195	-.036	-.233	-.356
	eegf2	-.466	-.336	-.216	.064	.106	.273	-.024	-.016	-.574
	eegf3	-.399	.011	-.035	-.004	-.140	.486	-.230	.046	-.480
	eegf4	-.398	.064	-.109	.015	-.222	.454	-.216	.059	-.395
	eegf7	-.491	-.188	-.131	-.234	-.045	.476	-.179	-.030	-.510
	eegf8	-.325	-.195	-.105	-.144	-.004	.298	-.120	-.133	-.404
	eegc3	-.163	.266	-.011	-.073	-.223	.476	-.349	-.002	-.222
	eegc4	-.204	.130	.150	-.134	-.256	.377	-.293	.007	-.269
	eegt3	-.525	-.118	-.071	-.092	-.023	.421	-.082	.130	-.652
	eegt4	-.401	-.272	-.145	-.097	.115	.232	.036	-.087	-.505
	eegt5	-.262	-.115	.064	-.090	-.004	.282	-.079	.011	-.464
	eegt6	-.288	-.228	-.077	-.006	.049	.281	-.074	-.070	-.443
	eegp3	-.195	-.072	-.029	-.025	-.131	.328	-.232	-.019	-.379
	eegp4	-.354	-.178	-.159	-.103	-.038	.409	-.171	-.047	-.484
	eego1	-.223	-.019	-.091	.107	-.073	.262	-.139	-.053	-.368
	eego2	-.337	-.264	-.057	.076	.041	.041	.104	-.226	-.330

Note: Correlations ≥ .400 are significant at .05 level; one-tailed tests of significance[2]

Table 6, continued: *Pearson Correlations between all Variables for Age 4½*

agegroup		cbqIM	cbqIC	cbqLP	cbqSE	cbqSD	cbqSH	cbqSL	cbqSURG	cbqNEG
4.5-years (n = 18)	TT									
	SS									
	DN									
	YN									
	VF									
	DCCS									
	WM5									
	PPVT									
	cbqAL									
	cbqAN									
	cbqAP									
	cbqAF									
	cbqAS									
	cbqDS									
	cbqSO									
	cbqFE									
	cbqHP									
	cbqIM	1.000								
	cbqIC	-.256	1.000							
	cbqLP	-.272	.205	1.000						
	cbqSE	-.024	.013	.059	1.000					
	cbqSD	.031	-.348	.078	.397	1.000				
	cbqSH	-.847	-.004	.127	.116	.164	1.000			
	cbqSM	-.042	.538	.517	.289	-.346	-.182	1.000		
	cbqSURG	.813	-.095	.056	.168	.191	-.805	.224	1.000	
	cbqNEG	-.116	-.659	.191	.096	.698	.287	-.414	.046	1.000
	cbqEFFC	-.150	.395	.580	.711	.150	.044	.654	.182	.002
	eegf1	-.294	.157	.082	.044	-.090	.385	-.178	-.363	-.110
	eegf2	-.427	.005	.107	.121	-.064	.525	-.110	-.565	-.046
	eegf3	-.497	.043	.153	-.111	-.007	.597	-.212	-.493	.176
	eegf4	-.367	-.089	.142	-.159	.038	.600	-.290	-.480	.194
	eegf7	-.508	-.026	-.058	-.109	-.035	.622	-.451	-.560	.079
	eegf8	-.364	-.011	.015	.077	.045	.579	-.308	-.456	.013
	eegc3	-.176	-.134	-.399	-.070	.184	.405	-.508	-.265	.303
	eegc4	-.251	-.071	-.211	.062	.306	.515	-.558	-.291	.261
	eegt3	-.594	.163	.099	-.028	.102	.676	-.277	-.625	.139
	eegt4	-.442	.208	.208	-.096	-.053	.488	-.074	-.493	-.071
	eegt5	-.379	.151	.194	-.077	-.010	.440	-.078	-.374	.050
	eegt6	-.332	.084	.094	-.097	-.136	.319	-.079	-.367	-.034
	eegp3	-.433	-.089	-.073	.294	.202	.676	-.161	-.428	.150
	eegp4	-.536	-.050	-.023	.195	.012	.697	-.246	-.547	.071
	eego1	-.289	-.001	-.057	.223	-.068	.476	-.118	-.378	.055
	eego2	-.364	.272	.140	.206	-.112	.505	-.025	-.396	-.180

Note: Correlations ≥ .400 are significant at .05 level; one-tailed tests of significance[2]

Table 6, continued: *Pearson Correlations between all Variables for Age 4½*

agegroup		cbqEFFC	eegf1	eegf2	eegf3	eegf4	eegf7	eegf8	eegc3	eegc4
4.5-years (n = 18)	TT									
	SS									
	DN									
	YN									
	VF									
	DCCS									
	WM5									
	PPVT									
	cbqAL									
	cbqAN									
	cbqAP									
	cbqAF									
	cbqAS									
	cbqDS									
	cbqSO									
	cbqFE									
	cbqHP									
	cbqIM									
	cbqIC									
	cbqLP									
	cbqSE									
	cbqSD									
	cbqSH									
	cbqSM									
	cbqSURG									
	cbqNEG									
	cbqEFFC	1.000								
	eegf1	.074	1.000							
	eegf2	.125	.857	1.000						
	eegf3	.009	.818	.764	1.000					
	eegf4	-.058	.761	.787	.921	1.000				
	eegf7	-.183	.796	.693	.854	.796	1.000			
	eegf8	-.022	.878	.855	.826	.869	.877	1.000		
	eegc3	-.245	.494	.375	.709	.658	.675	.585	1.000	
	eegc4	-.122	.709	.541	.795	.767	.819	.810	.845	1.000
	eegt3	.037	.805	.754	.931	.832	.819	.798	.655	.810
	eegt4	.053	.873	.887	.884	.843	.716	.837	.448	.640
	eegt5	.041	.769	.720	.868	.741	.683	.719	.486	.656
	eegt6	.010	.799	.824	.811	.696	.635	.710	.437	.558
	eegp3	.080	.573	.704	.687	.733	.702	.843	.594	.697
	eegp4	.027	.729	.781	.756	.765	.847	.919	.596	.726
	eego1	.138	.652	.741	.741	.748	.597	.774	.626	.661
	eego2	.279	.789	.778	.740	.771	.663	.853	.399	.683

Note: Correlations ≥ .400 are significant at .05 level; one-tailed tests of significance[2]

Table 6, continued: *Pearson Correlations between all Variables for Age 4½*

agegroup		eegt3	eegt4	eegt5	eegt6	eegp3	eegp4	eego1	eego2
4.5-years (n = 18)	TT								
	SS								
	DN								
	YN								
	VF								
	DCCS								
	WM5								
	PPVT								
	cbqAL								
	cbqAN								
	cbqAP								
	cbqAF								
	cbqAS								
	cbqDS								
	cbqSO								
	cbqFE								
	cbqHP								
	cbqIM								
	cbqIC								
	cbqLP								
	cbqSE								
	cbqSD								
	cbqSH								
	cbqSM								
	cbqSURG								
	cbqNEG								
	cbqEFFC								
	eegf1								
	eegf2								
	eegf3								
	eegf4								
	eegf7								
	eegf8								
	eegc3								
	eegc4								
	eegt3	1.000							
	eegt4	.880	1.000						
	eegt5	.860	.902	1.000					
	eegt6	.766	.907	.913	1.000				
	eegp3	.644	.642	.574	.532	1.000			
	eegp4	.714	.692	.562	.593	.885	1.000		
	eego1	.692	.705	.640	.670	.761	.802	1.000	
	eego2	.748	.801	.669	.660	.695	.779	.815	1.000

Note: Correlations ≥ .400 are significant at .05 level; one-tailed tests of significance[2]

Table 7: *Pearson Correlations among the Five Working Memory Tasks*

	Tongue task	Simon-says task	Day-night task	Yes-no task
Tongue task	.			
Simon-says task	.207	.		
Day-night Stroop task	.151	.182	.	
Yes-no task	**.339***	**.387****	**.400****	**.**
DCCS	**.398****	**.437****	**.471****	**.422****

**p* < .05, ***p* < .01; *one-tailed tests of significance*

Table 8: *Pearson Correlations among the Five Working Memory Tasks by Age*

	Tongue task	Simon-says task	Day-night task	Yes-no task
Age 3½ (n = 11)				
Tongue task	.			
Simon-says task	-.071	.		
Day-night Stroop task	-.057	**-.519***	.	
Yes-no task	.304	-.152	.179	.
DCCS	.384	.275	-.111	.440
Age 4 (n = 17)				
Tongue task	.			
Simon-says task	.202	.		
Day-night Stroop task	-.018	.334	.	
Yes-no task	.345	**.700****	**.538***	.
DCCS	.286	**.432***	**.582****	.395
Age 4½ (n = 21)				
Tongue task	.			
Simon-says task	**.822****	.		
Day-night Stroop task	**.773****	**.836****	.	
Yes-no task	**.414***	**.470***	.352	.
DCCS	**.754****	**.944****	**.858****	**.429***

*$p < .05$, **$p < .01$; *one-tailed tests of significance*

Table 9: *Descriptive Statistics of the Five Working Memory Tasks by Age*

	n	*Range*	*Mean*	*Standard Deviation*
Tongue task				
3½-years	11	33-100	90.88	21.64
4-years	17	0-100	87.06	30.16
4½-years	18	50-100	95.37	13.77
Simon-says task				
3½-years	11	0-100	77.27	39.45
4-years	17	0-100	73.53	42.82
4½-years	18	60-100	7.78	9.43
Day-night task				
3½-years	11	43.75-100	78.98	30.93
4-years	17	0-100	74.26	25.18
4½-years	18	25-100	81.94	17.00
Yes-no task				
3½-years	11	0-93.75	49.43	30.93
4-years	17	0-100	60.66	37.03
4½-years	18	0-100	65.28	34.65
DCCS				
3½-years	11	0-100	73.64	40.56
4-years	17	0-100	79.00	39.04
4½-years	18	0-100	91.02	24.07
WM_5 SCORE				
3½-years	11	45-95	74.04	16.46
4-years	17	15-98.75	74.90	25.21
4½-years	18	27-100	86.28	16.31

Table 10: *Summary of Regression Procedures Investigating Age and EEG (F3) as Predictors of Working Memory Performance*

	df1	*df2*	*Beta*	*t*	*Sig*	*R*	*R^2*	*R^2 Change*	*Sig.*
Step 1: AGE									
Model 1									
Age D1	2	43	-.271	-1.672	.102	.282	.08	.08	.167
Age D2			-.257	-1.590	.119				
Step 2: AGE & EEG *									
Model 2									
Age D1	1	42	-.275	-1.756	.086	.401	.161	.081	.050
Age D2			-.270	-1.725	.092				
EEG (F3)			.285	2.014	.050				
Step 3: AGE, EEG, AGE x EEG									
Model 2									
Age D1	2	40	-.934	-.726	.472	.414	.171	.011	.776
Age D2			-.172	-.155	.877				
EEG (F3)			.231	.802	.428				
Age D1 x EEG (F3)			.670	.516	.609				
Age D2 x EEG (F3)			-.098	-.087	.931				

* Indicates that overall model is significant.

Table 11: *Pearson Correlations among the CBQ Scales of Interest*

	EFFC	*IC*	*AF*	*LP*	*SE*	***SURG***	*AL*	*AP*	*HP*	*SH*	*IM*	*AN*
EFFORTFUL CONTROL	.											
Inhibitory control (IC)	**.75****	.										
Attention focusing (AF)	**.76****	**.40****	.									
Low pleasure (LP)	**.74****	**.54****	**.54****	.								
Perceptual sensitivity (SE)	**.45****	.10	.04	.018	.							
SURGENCY	-.06	-.12	-.05	-.11	.10	.						
Activity level (AL)	**-.28***	**-.39***	-.23	**-.28***	.129	**.78****	.					
Approach (AP)	-.05	**-.32***	-.13	-.08	**.39****	**.54****	**.58****	.				
High pleasure (HP)	.01	.02	-.01	.00	.01	**.85****	**.57****	**.25***	.			
Shyness (SH)	-.08	-.20	-.14	-.01	.14	**-.66****	-.19	.06	**-.51****	.		
Impulsivity (IM)	**-.32***	**-.32***	**-.27***	**-.36****	.07	**.77****	**.59****	**.48****	**.60****	**-.51****	.	
Anger/frustration (AN)	**-.33***	**-.59****	-.14	**-.26***	.09	**.34***	**.57****	**.63****	.15	.18	**.34***	.

*$p < .05$, **$p < .01$

Table 12: *Pearson Correlations between the Working Memory Tasks and the CBQ Scales*

	Tongue	*Simon*	*DN*	*YN*	*DCCS*	*WM$_5$*
AGE 3 ½ (n = 11)						
Effortful Control	-.44	.30	..20	-.29	**-.62***	-.35
Inhibitory control	-.50	.11	.42	-.10	-.50	-.26
Attention focusing	-.33	.44	-.10	-.25	**-.53***	-.25
Low pleasure	-.31	.13	.04	-.14	**-.56***	-.34
Perceptual sensitivity	-.13	.13	.17	-.37	-.27	-.20
Surgency	-.12	-.13	.29	-.32	-.03	-.16
Activity level	.32	-.01	.26	-.05	**.61***	.41
Approach	.05	-.33	.29	-.34	.05	-.18
High pleasure	**-.59***	-.03	.01	-.41	-.42	**-.53***
Shyness	.16	.04	-.26	.14	.36	.23
Impulsivity	.28	-.17	.01	-.12	.11	.01
Anger/frustration	.23	.06	-.01	-.33	.37	.15
AGE 4 (n = 17)						
Effortful Control	.15	**.51***	.22	.34	.40	**.48***
Inhibitory control	.29	**.42***	.24	.33	**.46***	**.50***
Attention focusing	-.05	**.63****	.18	.29	.16	.37
Low pleasure	.11	.41	.27	.24	.34	.40
Perceptual sensitivity	.13	-.15	-.12	.07	.24	.05
Surgency	.23	-.01	-.01	.11	.05	.10
Activity level	-.17	-.07	-.12	-.08	-.24	-.19
Approach	-.03	.29	-.05	.16	-.26	-.15
High pleasure	.03	-.10	.09	-.01	.165	.04
Shyness	**-.64****	-.29	-.04	-.21	-.30	**-.41***
Impulsivity	.33	-.22	-.28	-.03	-.32	-.15
Anger/frustration	-.31	-.34	-.09	-.14	.01	-.25
AGE 4½ (n = 18)						
Effortful Control	-.30	-.13	-.03	.09	-.07	-.06
Inhibitory control	.18	.11	.23	**.45***	.11	.32
Attention focusing	-.33	-.13	-.07	-.08	.03	-.11
Low pleasure	-.05	.01	.05	.08	.02	.04
Perceptual sensitivity	**-.41***	-.24	-.20	-.12	-.25	-.27
Surgency	**-.50***	-.31	**-.43***	.20	-.29	-.21
Activity level	-.35	-.20	**-.42***	.20	.21	-.14
Approach	-.32	-.17	-.12	.31	-.13	-.01
High pleasure	**-.42***	-.38	**-.52***	.04	-.38	-.32
Shyness	**.40***	.22	.30	-.16	.20	.14
Impulsivity	**-.40***	-.35	**-.45***	-.01	-.34	-.31
Anger/frustration	-.23	-.15	-.36	.07	-.07	-.12

**p* < .05, ***p* < .01

Table 13: *Summary of Regression Procedure Investigating Age and Temperament as Predictors of Working Memory Function*

	df1	*df2*	*Beta*	*t*	*Sig*	*R*	R^2	R^2 *Change*	*Sig.*
Step 1: AGE									
Model 1									
Age D1	2	43	-.217	-1.672	.102	.282	.08	.08	.167
Age D2			-.257	-1.590	.119				
Step 2: AGE & TEMP *									
Model 2									
Age D1	1	42	-.257	-1.620	.113	.372	.138	.058	.099
Age D2			-.335	-2.028	.049				
CBQ (IC)			.256	1.685	.099				
Step 3: AGE, TEMP, AGE x TEMP *									
Model 2									
Age D1	2	40	-1.408	-1.228	.227	.499	.249	.111	.064
Age D2			1.121	1.049	.301				
TEMP (IC)			.295	1.123	.268				
Age D1 x TEMP (IC)			1.171	1.024	.312				
Age D2 x TEMP (IC)			-1.492	-1.317	.195				

* Indicates that overall model is significant.

Table 14: *Summary of Regression Procedure Investigating Language as a Predictor of Working Memory Performance*

	df1	*df2*	*Beta*	*t*	*Sig*	*R*	*R^2*	*R^2 Change*	*Sig.*
Step 1: AGE									
Model 1									
Age D1	2	43	-.217	-1.672	.102	.282	.08	.08	.167
Age D2			-.257	-1.590	.119				
Step 2: AGE & LANG *									
Model 2									
Age D1	1	42	-.051	-.360	.721	.630	.396	.317	.000
Age D2			-.043	-.305	.762				
LANG (PPVT)			.609	4.694	.000				
Step 3: AGE, LANG, AGE x LANG *									
Model 2									
Age D1	2	40	-.865	-1.132	.264	.644	.414	.018	.545
Age D2			-.175	-.240	.812				
LANG (PPVT)			.508	2.824	.007				
Age D1 x LANG (PPVT)			.795	1.092	.281				
Age D2 x LANG (PPVT)			.099	.142	.888				

*Indicates that overall model is significant.

Table 15: *Language Receptivity as a Predictor of Working Memory Function for Each Age Group*

	df1	*df2*	R^2	*Beta*	*t*	*Sig*
Age 3½ *						
LANG (PPVT)	1	9	.374	.611	2.318	.046
Age 4 *						
LANG (PPVT)	1	15	.306	.553	2.570	.021
Age 4½ *						
LANG (PPVT)	1	16	.488	.699	3.904	.001

* Indicates that the overall model was significant.

Table 16: *Summary of the Hierarchical Regression Predicting Working Memory Function with Multiple Variables*

	df1	*df2*	*Beta*	*t*	*Sig*	*R*	R^2	R^2 *Change*	*Sig*
Model 1									
Age D1	2	43	-.271	-1.672	.102	.282	.080	.080	.167
Age D2			-.257	-1.590	.119				
Model 2 *									
Age D1	1	42	-.275	-1.756	.086	.401	.161	.081	.050
Age D2			-.270	-1.725	.092				
EEG (F3)			.285	2.014	.050				
Model 3 *									
Age D1	1	41	-.261	-1.708	.095	.468	.219	.058	.088
Age D2			-.348	-2.184	.035				
EEG (F3)			.285	2.062	.046				
TEMP (IC)			.255	1.748	.088				
Model 4 *									
Age D1	1	40	-.073	-.509	.613	.645	.416	.197	.001
Age D2			-.109	-.708	.483				
EEG (F3)			.114	.880	.384				
TEMP (IC)			.115	.860	.395				
LANG (PPVT)			.535	3.678	.001				

* Indicates that overall model is significant.

Table 17: *Frequency Distribution of the WM2 Scores at Age 3½*

		Frequency	***Percent***	***Cumulative Percent***
WM_2 Score	34.38	1	9.1	9.1
	46.88	2	18.2	27.3
	50.00	1	9.1	36.4
	59.38	2	18.2	54.5
	62.50	1	9.1	63.6
	84.38	2	18.2	81.8
	87.50	1	9.1	90.9
	90.63	1	9.1	100.0
	Total	11	100.0	100.0

Note: All children with WM_2 scores $\geq$ 84.38 were placed into the high performance group, and all children with WM_2 scores $\leq$ 62.50 were placed into the low performance group.

Table 18: *Pearson Correlations among the Working Memory Tasks for the Total Sample of 3½-Year-Olds*

	Tongue task	Simon-says task	Day-night task	Yes-no task
Tongue task	.			
Simon-says task	.348	.		
Day-night Stroop task	.401*	.386*	.	
Yes-no task	.322	.217	.691**	.
DCCS	.064	.503*	.428*	.505*

**p* < .05, ***p* < .01

Table 19: *Pearson Correlations between the Working Memory Tasks and the CBQ Scales of Interest at Age 3½ with the Total Sample*

	Tongue	*Simon*	*DN*	*YN*	*DCCS*	*WM*$_5$
AGE 3 ½ (n = 20)						
Effortful Control	.071	**.423***	**.434***	.132	.079	.322
Inhibitory control	-.016	.193	.275	.056	.054	.159
Attention focusing	.024	**.519****	**.408***	.201	.249	**.404***
Low pleasure	.178	.371	**.460***	.256	.049	.362
Perceptual sensitivity	.096	.110	.145	-.130	-.227	-.004
Surgency	.221	.112	.205	-.113	-.192	.061
Activity level	-.123	-.011	.057	-.040	.215	.037
Approach	.092	-.291	-.052	-.232	-.291	-.228
High pleasure	.181	.175	.115	-.174	-.326	-.010
Shyness	**-.380***	-.286	-.340	-.053	.166	-.242
Impulsivity	.299	-.042	.136	.060	-.239	.042
Anger/frustration	-.094	-.220	-.128	-.203	-.036	-.188

*$p < .05$, **$p < .01$

Table 20: *Language Receptivity as a Predictor of Working Memory Function for Each Age Group with the Total Sample*

	df1	*df2*	*R^2*	*Beta*	*t*	*Sig*
Age 3½ *						
LANG (PPVT)	1	17	.256	.506	2.419	.027
Age 4 *						
LANG (PPVT)	1	18	.386	.621	3.365	.003
Age 4½ *						
LANG (PPVT)	1	19	.574	.758	5.060	.000

* Indicates that overall model is significant.

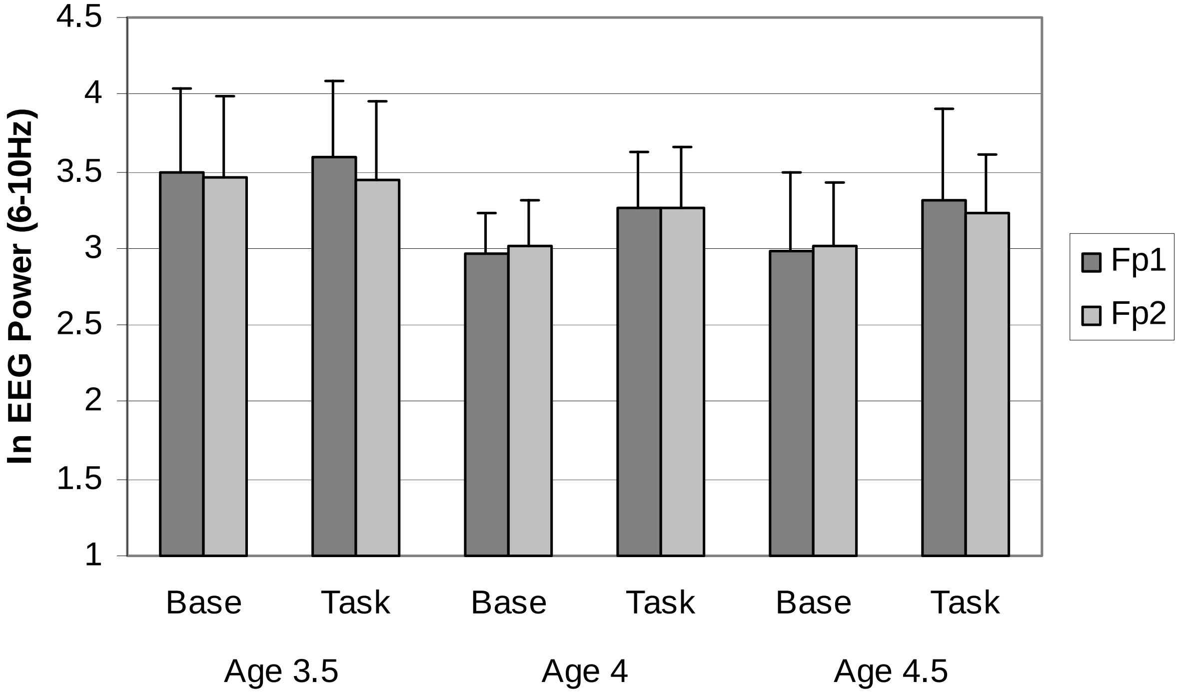


Figure 1: Baseline and task EEG power values (ln 6-10Hz) from frontal pole (Fp1/Fp2) scalp locations for the three age groups. There is an increase in baseline-to-task ln EEG power at age 4 only.

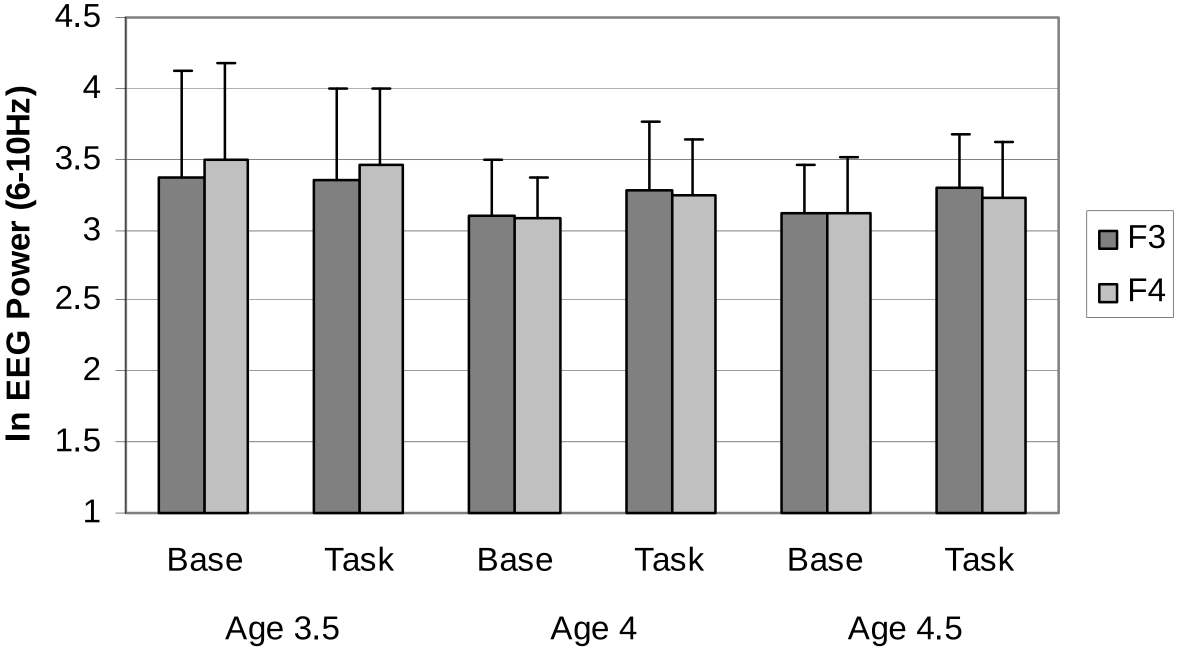


Figure 2: Baseline and task EEG power values (ln 6-10Hz) from medial frontal (F3/F4) scalp locations for the three age groups. There is an increase in baseline-to-task ln EEG power at age 4 and age 4½.

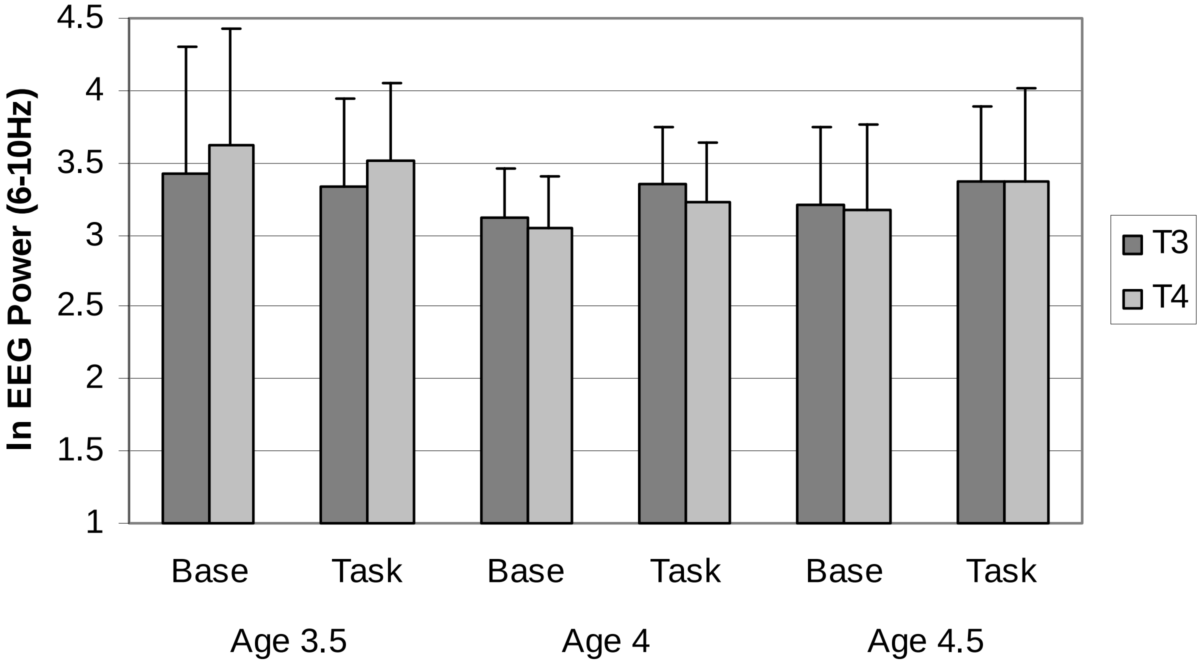


Figure 3: Baseline and task EEG power values (ln 6-10Hz) from anterior temporal (T3/T4) scalp locations for the three age groups. There is an increase in baseline-to-task ln EEG power at age 4 only.

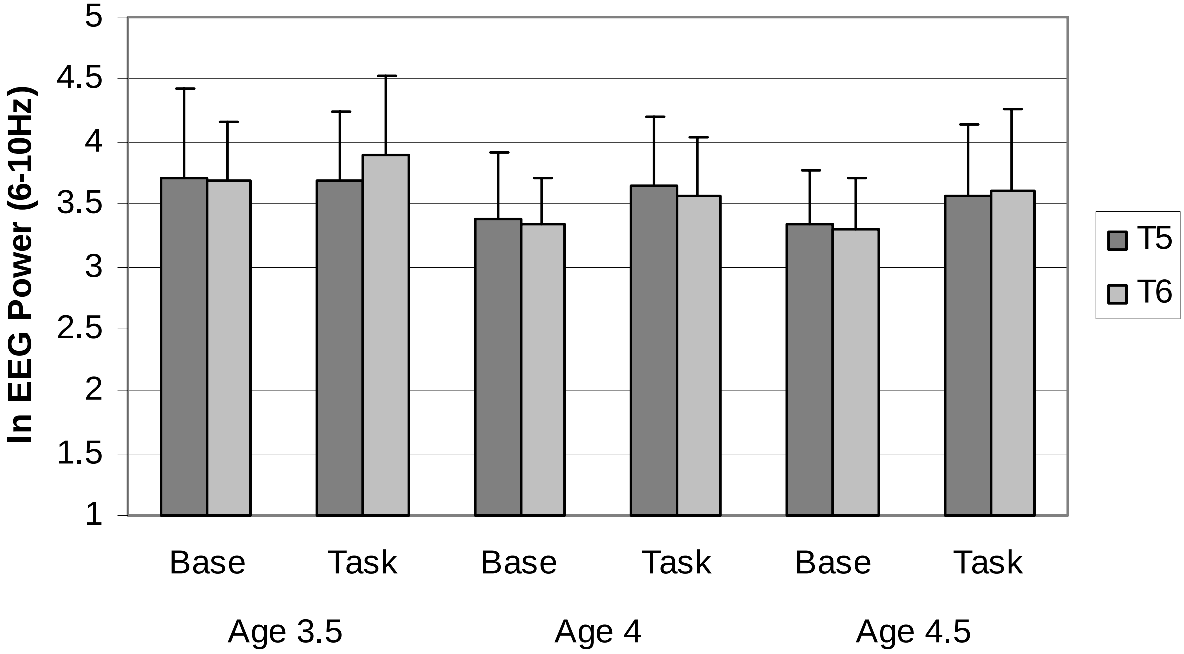


Figure 4: Baseline and task EEG power values (ln 6-10Hz) from posterior temporal (T5/T6) scalp locations for the three age groups. There is an increase in baseline-to-task ln EEG power at age 4 and age 4½.

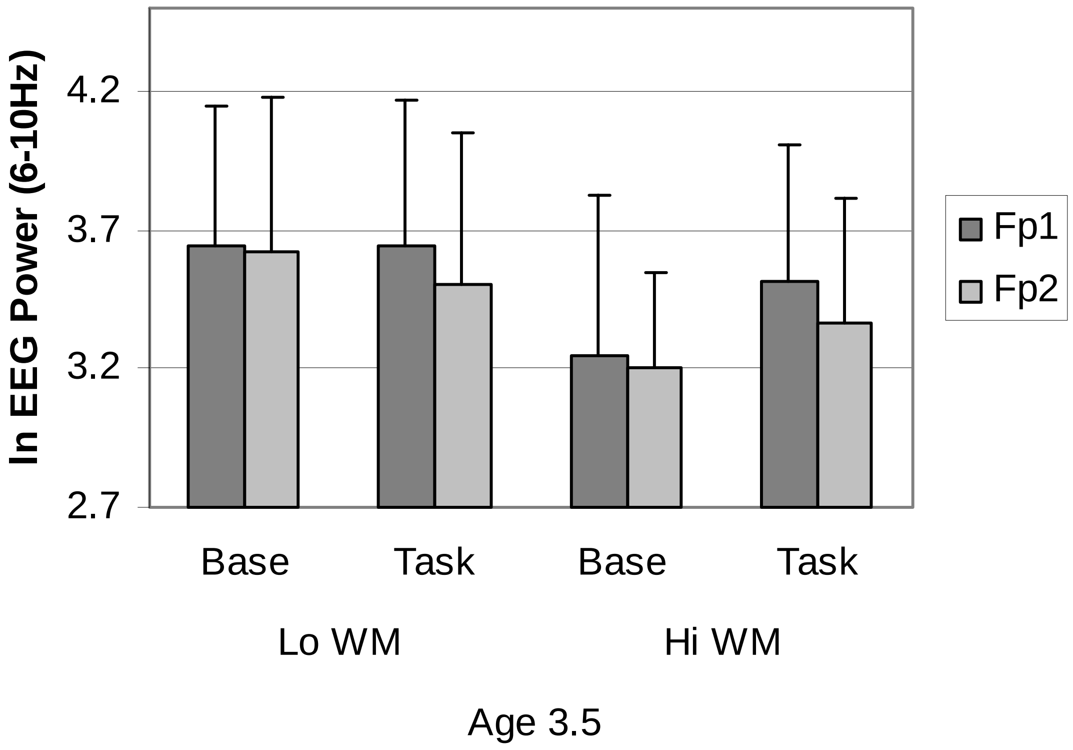


Figure 5: Baseline-to-task ln EEG power values for the frontal pole scalp location at age 3½.

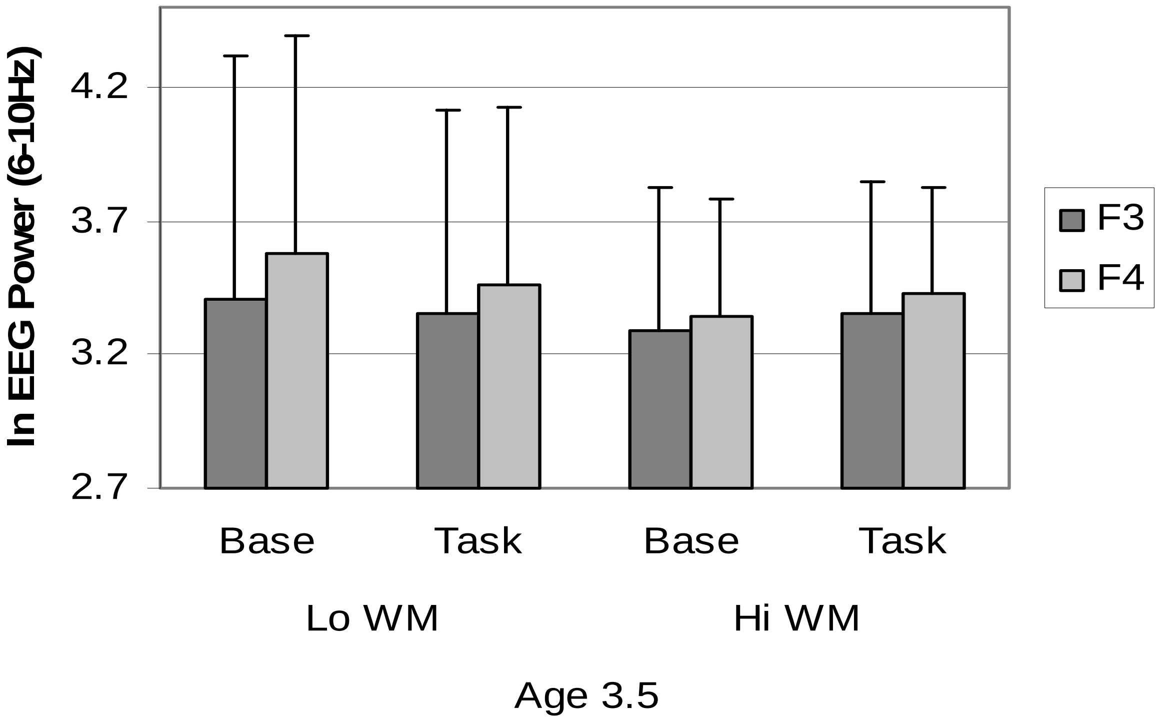


Figure 6: Baseline-to-task ln EEG power values for the medial frontal scalp location at age 3½.

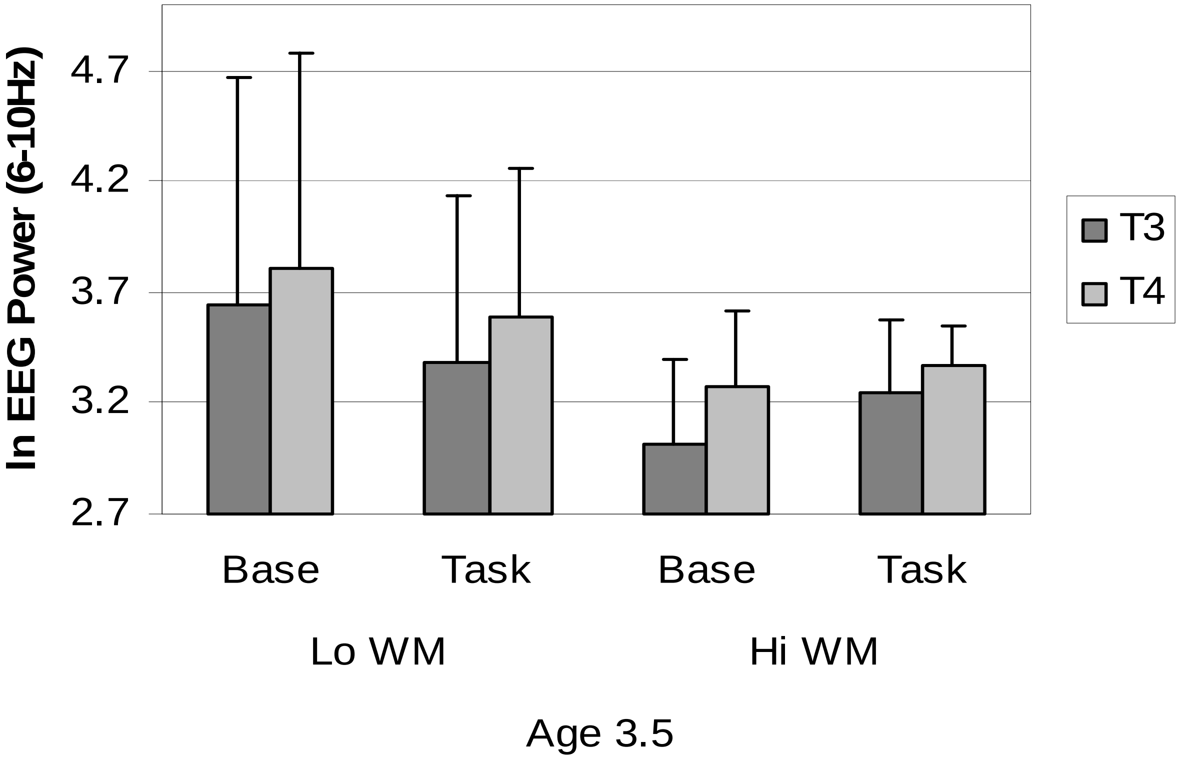


Figure 7: Baseline-to-task ln EEG power values for the anterior temporal scalp location at age 3½.

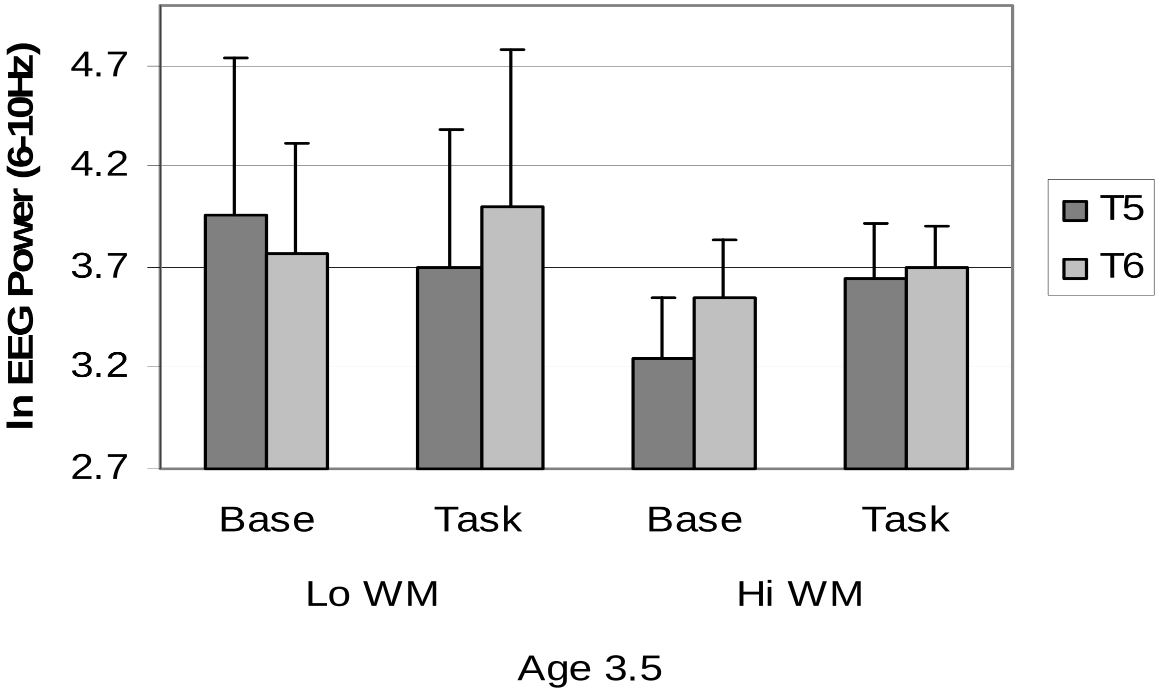


Figure 8: Baseline-to-task ln EEG power values for the posterior temporal scalp location at age 3½.

Appendices

Appendix A – Developmental Science Database Recruitment Letter

(date)

Dear Parent,

Greetings from the Psychology Department at Virginia Tech! We are two researchers doing a study of memory, language, and temperament with preschoolers in the New River Valley area. We are looking for 60 children (20 3½-year-olds, 20 4-year-olds, and 20 4½-year-olds) and their parents to join us in this study. We invite you and your child to participate!

Participation in this project will involve one 45-minute visit to the Developmental Cognitive Neuroscience Lab at Virginia Tech. We will play some games that will challenge your child to use his/her memory and attention skills, and we will also play some vocabulary games to determine how memory and language are related. Some of these games will be played while your child wears our little stretchy EEG cap, so we can see what the brain is doing while s/he plays our games. There will also be some questions that we will want you to answer about your child's temperament and general patterns of behavior.

You may already be familiar with our infant and child research program at Virginia Tech if your child participated in our on-going Infant Development Project or in a study at the Infant Speech Perception lab (formerly behind Bogen's Restaurant). Or you might have seen the news article about our research labs in the *New River Current* last July.

Would you be interested in hearing more about the preschool study? We will be giving you a call in the next couple of weeks. Agreeing to talk with us over the phone does not obligate you to participate. We want to tell you all the details before you decide whether or not you and your child would like to participate. In the meantime, feel free to visit the web site for our research lab.

http://www.psyc.vt.edu/devcogneuro

If you wish, you can contact us at 231-2320 (research lab) and by email (Ms. Wolfe's address is *cwolfe@vt.edu*). Thank you and we look forward to talking with you!

Sincerely yours,

Martha Ann Bell, PhD	Christy Wolfe, MA
Associate Professor of Psychology	Graduate Student

Appendix B – Preschool and Daycare Recruitment Letter

(date)

Dear Parent,

Greetings from the Psychology Department at Virginia Tech! We are two researchers doing a study of memory, language, and temperament with preschoolers in the New River Valley area. We are looking for 60 children (20 3½-year-olds, 20 4-year-olds, and 20 4½-year-olds) and their parents to join us in this study. We invite you and your child to participate!

Participation in this project will involve one 45-minute visit to the Developmental Cognitive Neuroscience Lab at Virginia Tech. We will play some games that will challenge your child to use his/her memory and attention skills, and we will also play some vocabulary games to determine how memory and language are related. Some of these games will be played while your child wears our little stretchy EEG cap, so we can see what the brain is doing while s/he plays our games. There will also be some questions that we will want you to answer about your child's temperament and general patterns of behavior.

You may already be familiar with our infant and child research program at Virginia Tech if your child participated in our on-going Infant Development Project or in a study at the Infant Speech Perception lab (formerly behind Bogen's Restaurant). Or you might have seen the news article about our research labs in the *New River Current* last July.

Would you be interested in hearing more about the preschool study? You can contact us at the phone number or the email address listed below. Agreeing to talk with us over the phone does not obligate you to participate. We want to tell you all the details before you decide whether or not you and your child would like to participate. In the meantime, feel free to visit the web site for our research lab.

http://www.psyc.vt.edu/devcogneuro

If you wish, feel free to call us at your convenience. We can be reached at 231-2320 (research lab) and by email (Ms. Wolfe's address is *cwolfe@vt.edu*). Thank you and we look forward to talking with you!

Sincerely yours,

Martha Ann Bell, PhD	Christy Wolfe, MA
Associate Professor of Psychology	Graduate Student

Appendix C – Informed Consent (Parent)

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Parent Permission Form

Title of Project: “Electrophysiological, Temperamental, and Linguistic Correlates of Working Memory in Early Childhood

Investigators: Christy Wolfe, MA & Martha Ann Bell, PhD

I. Purpose of this Research

You and your child have been invited to be a part of a research study investigating the development of memory from 3½-to-4½ years of age. Specifically, we are examining how brain-wave activity, heart rate, temperament, and language abilities are related to memory skills at 3½, 4, and 4½ years of age. What we learn from this study will help us better understand how children develop the important cognitive skills of attention and memory. We hope to have 60 children (i.e., 20 3½-year-olds, 20 4-year-olds, and 20 4-½-year-olds) and parents from the New River Valley area help us with this project.

II. Procedures

This study involves one 45-minute visit to the Developmental Cognitive Neuroscience Lab (Williams 339) at Virginia Tech. You will remain in the room with your child throughout the entire visit. This study also involves two questionnaires (General Information Questionnaire and the Children’s Behavior Questionnaire). We will ask you to try to complete these forms at home prior to your child’s visit to our research lab.

In order to measure brain activity during the session, we will place a stretchy cap with sensors on your child’s head. The cap looks and fits like a swim cap. Gel will then be applied to your child’s hair through little holes in the cap. In addition, we will be placing two small sticky patches on your child’s chest to help us collect heart rate activity. These procedures are similar to those used in a doctor’s office and are not harmful to your child. While brain-wave activity and heart rate activity are being recorded for three minutes, your child will be watching a brief Sesame Street video. Brain-wave activity and heart rate activity will also be recorded during three of the games noted in the next paragraph.

There are four brief games that require your child to “remember the rules” and two vocabulary games that we will play. The first four games are tricky, and they are designed to be difficult for your child to remember the simple rules. For example, game 1 (Simon-Says) requires your child to perform an action when one stuffed-animal instructs him/her to do so but not when the second stuff-animal instructs him/her to do so. Game 2 requires your child hold an M&M (or a goldfish cracker) on his/her tongue without chewing it for increasing lengths of time. Game 3 requires your child to say “day” when shown a picture of a nighttime scene and to say “night” when shown a picture of a daytime scene. Game 4 challenges your child to say “yes” when the experimenter shakes her head no and to say “no” when the experimenter nods her head yes. The two vocabulary games will be played last. There are no “rules” for these games. We just want to know how memory and language are related.

After the brain wave and heart rate recordings associated with games 3 and 4 and one of the language games, the cap and sticky patches will be removed and the gel will be washed from your child’s hair with warm water and a clean wash cloth.

III. Risks

There is minimal risk associated with this research project. The brain-wave and heart rate procedures are similar to that done in a doctor’s office and are not harmful. All brain-wave equipment is disinfected after each use. The heart rate patches are disposable. If your child has an allergy to skin lotions, please inform us so that we can discuss the allergy and determine if any procedural changes need to be made. Our EEG gels are water based, but do contain the same preservatives that are used in everyday skin lotions.

IV. Benefits of This Research

There are no personal benefits for you or your child being in this study. However, by being a part of this research, you and your child will help us learn more about memory and language during early childhood. When we are done with the study, we will send you a letter telling you about what was learned from this research.

V. Extent of Anonymity and Confidentiality

Information about your child's game playing will be labeled by code number, not by your child's name. Information linking child name and code number will be kept in a file and locked in a file drawer. Only Dr. Bell and Ms. Wolfe will be able to see this file. Your child will be videotaped during the lab procedure. This allows us to go back at a later date and you're your child's memory behaviors. Videotapes will be labeled by code number not by child's name. Tapes will be stored in our research lab at Virginia Tech and only Research Assistants working on this research project will be able to look at them. Dr. Bell will supervise the storing of these videotapes. Tapes will be erased five years after publication of the results of this study.

VI. Compensation

Your child will receive a small toy for participating in this study. We also believe that your child will find our games fun to play.

VII. Freedom to Withdraw

You or your child may withdraw from participation in this research study at any time without penalty. Your child will still receive the gift.

VIII. Approval of Research

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University and by the Department of Psychology at Virginia Tech.

IX. Parent's Responsibilities

My child and I voluntarily agree to participate in this study.

X. Parent's Permission

I have read and understand the Parent Consent form. I have had all my questions answered. I give my voluntary consent for my child to participate in this project. I understand that I may decide for my child to not participate in this study at any time without penalty. ***I understand that I will be given a copy of this consent form.***

______________________________	_______________
Parent's signature	Date

Should I have any questions about this study, I may contact:

1) Christy Wolfe, MA
   Investigator, Graduate Student in Psychology, 231-2320
2) Martha Ann Bell, PhD
   Investigator, Associate Professor of Psychology, 231-2546
3) David W. Harrison, PhD
   Chair, Psychology Department Human Subjects Committee, 231-4422
4) Dr. David Moore
   Chair, IRB, CVM Phase II, 231-4991

Appendix D – Child Assent Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Child Assent Form

Title of Project:	“Electrophysiological, Temperamental, and Linguistic Correlates of Working Memory in Early Childhood”
Investigators:	Christy Wolfe, MA & Martha Ann Bell, PhD

I. Explanation of Research to Child

We’re going to play some fun games today. Some of the games are memory games and some are picture games. In one of the games we will use M&Ms (or goldfish crackers) and one of the games is like “Simon-says”. Have you ever played Simon-says before? Also, for some of these games, you will get to wear our cool cap that looks like this. (Shows EEG cap to child). At any time you can decide to stop playing these games. Just tell us, and we will stop.

II. Asking for Child’s Verbal Assent

Are you ready to play? Shall we get the games ready?

III. Witness Affirmation

The child verbally agreed to participate in this research study. I understand that the parent will receive a copy of this assent form.

____
Child’s name

______________________________ ____________________
Signature of witness Date

Appendix E – General Information Questionnaire

GENERAL INFORMATION QUESTIONNAIRE

Child ID number ______

Date of visit __________

1. Sex of child: M F

2. Date of birth: ___________

3. Birth order – This child is the ______ child from a sibling group of _____ children.

4. Has your child experienced any serious illness or problems in development?
_____ No
_____Yes – brief explanation ____

5. Has your child had any neurological problems, such as epilepsy, or seizures of any kind?
_____No
_____Yes – brief explanation ____

6. Has your child been diagnosed with any vision difficulties?
_____No
_____Yes – brief explanation ____

7. Has your child received any long-term medication?
_____No
_____Yes – brief explanation ____

8. Is your child ill or on any medications now?
_____No
_____Yes – brief explanation ____

9. Has your child shown an allergic reaction to anything?
_____No
_____Yes – brief explanation ____

10. Has your child ever had any skin irritations?
_____No
_____Yes – brief explanation ____

11. Which hand does your child use to feed him/herself?
_____Right
_____Left

12. Age of parents:
mother _______
father ________

13. Background information of parents:

A. **mother** – *I consider myself as:*
_____Hispanic
_____Non-Hispanic

father – *I consider myself as:*
_____Hispanic
_____Non-Hispanic

B. **mother** – *I described myself as:*
_____American Indian/Alaska Native
_____Asian
_____Native Hawaiian or
Other Pacific Islander
_____Black or African American
_____White
_____Other

father – *I described myself as:*
_____American Indian/Alaska Native
_____Asian
_____Native Hawaiian or
Other Pacific Islander
_____Black or African American
_____White
_____Other

14. Highest level of education completed (please note any “in progress”):

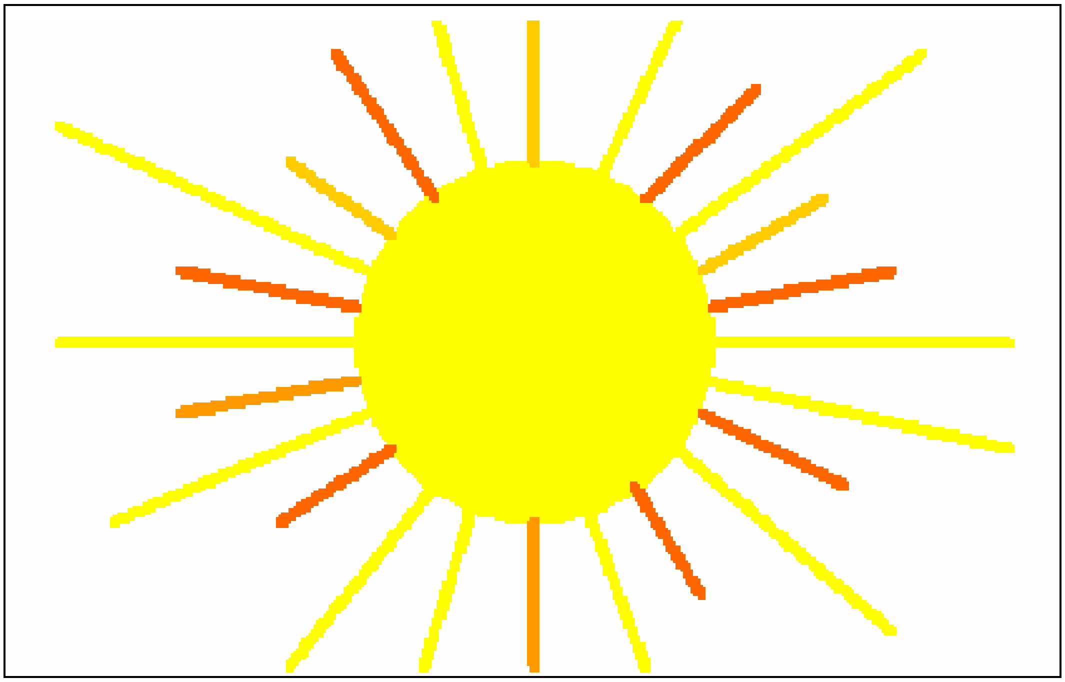
mother _____high school
_____technical school
_____college
_____graduate school

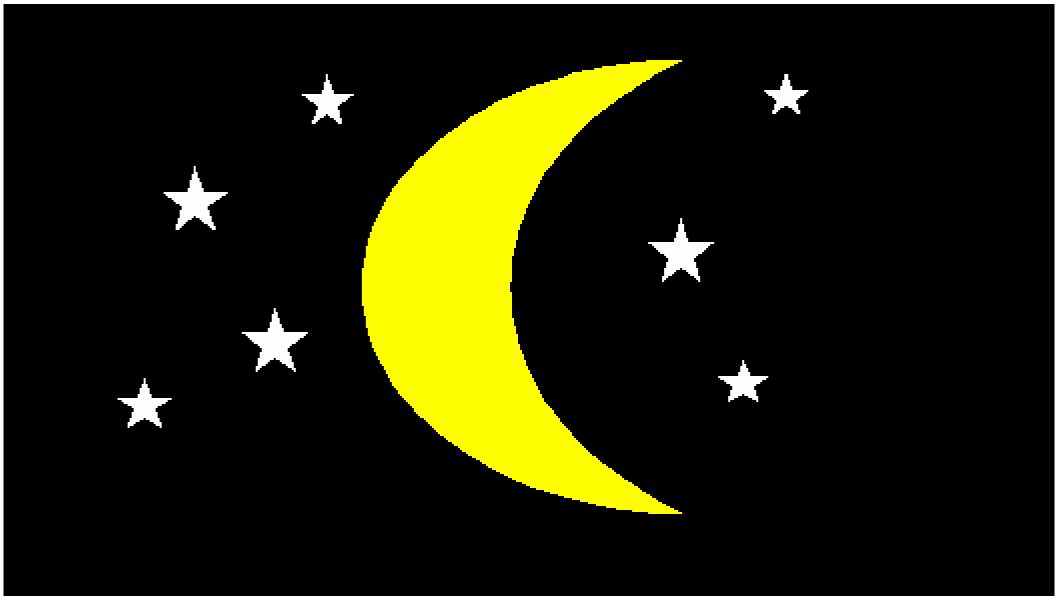
father _____high school
_____technical school
_____college
_____graduate school

15. Which hand do you prefer to use for each of these activities?
Please put R (right hand), L (left hand), or E (either hand).

	mother	**father**
a. Writing	_____	_____
b. Drawing	_____	_____
c. Throwing	_____	_____
d. Scissors	_____	_____
e. Toothbrush	_____	_____
f. Knife (without fork)	_____	_____
g. Spoon	_____	_____
h. Broom (upper hand)	_____	_____
i. Striking match (to hold match)	_____	_____
j. Opening jar (hand on lid)	_____	_____
* * * * * * * * * * * * *		
k. Which foot do you prefer to kick with?	_____	_____
l. Which eye do you use when using only one?	_____	_____

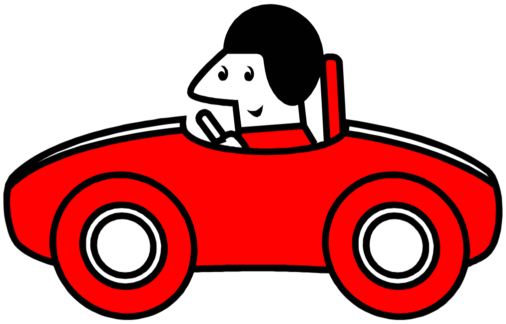
Appendix F – Stroop-like day-night stimuli

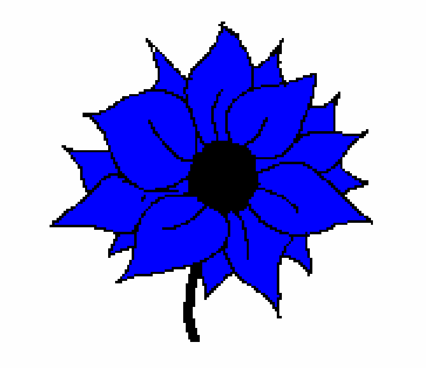




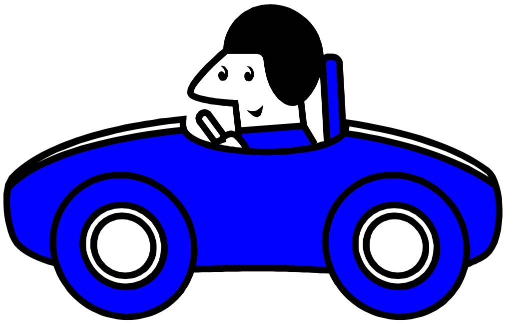
Appendix G – Dimensional Card Change Sort Stimuli

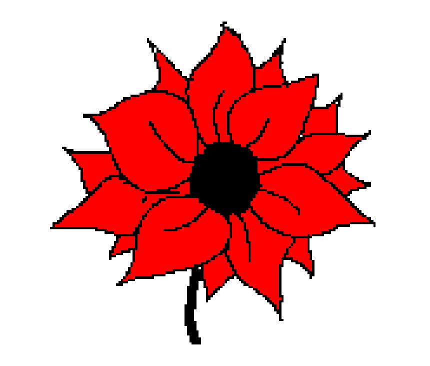
Target cards:





Test cards:





VITAE

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EDUCATION:

PhD, May 2005, Virginia Polytechnic Institute & State University

Major:	Psychological Sciences
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Dissertation:	"Regional differences in task-related brain electrical activity and sources of variability in executive function in early childhood"
Mentor:	Martha Ann Bell, PhD

MA, December 2000, East Tennessee State University

Major:	Experimental Psychology
Thesis:	"Male coercive sexual behavior as a function of target male resource-potential and respondent gender"
Advisor:	Otto Zinser, PhD

BS, May 1996, University of Virginia's College at Wise

Major:	Psychology
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PROFESSIONAL EXPERIENCE:

2000 – Present	Graduate Research Assistant, Developmental Cognitive Neuroscience Research Lab, Virginia Tech
2000 – 2004	Graduate Teaching Assistant, Department of Psychology, Virginia Tech
1999 – 2000	Research Assistant, James H. Quillen College of Medicine, East Tennessee State University
1999 – 2000	Adjunct Faculty, Department of Psychology, East Tennessee State University
1997 – 1999	Graduate Research Assistant, Office of Student Affairs, East Tennessee State University

PUBLICATIONS:

Wolfe, C. D., & Bell, M. A. (in press). *The integration of cognition and emotion during infancy and early childhood: Regulatory processes associated with the development of working memory*. *Brain and Cognition*.

Bell, M. A., & **Wolfe, C. D.** (2004). Emotion and cognition: An intricately bound developmental process. *Child Development, 75*, 366-370.

Wolfe, C. D., & Bell, M. A. (2004). Working memory and inhibitory control in early childhood: Contributions from electrophysiology, temperament, and language. *Developmental Psychobiology, 44*, 68-83.

BOOK CHAPTERS:

Bell, M.A., & **Wolfe, C.D.** (in press). Electroencephalographic (EEG) measures in cognitive developmental research. To appear in L.A. Schmidt & S.J. Sigalowitz (eds.), *Developmental Psychophysiology*. New York: Cambridge University Press.

MANUSCRIPTS UNDER REVIEW:

Bell, M. A., & **Wolfe, C. D.** (2004). Brain reorganization from infancy to early childhood: Evidence from EEG power and coherence during working memory tasks. Manuscript under review at *Developmental Neuropsychology*.

BOOK CHAPTERS IN PREPARATION:

Bell, M.A., & Wolfe, C.D. (in preparation). Cognitive neuroscience and early socioemotional development (working title). To appear in C.A. Brownell & C.B. Kopp (Eds.), *Transitions in early socioemotional development: The toddler years*. New York: Guilford.

Bell, M.A., Wolfe, C.D., & Adkins, D.R. (in preparation). Frontal lobe development during infancy and early childhood (working title). To appear in D. Coch, G. Dawson, & K.W. Fisher (Eds.), *Human behavior and the developing brain* (2nd ed.). New York: Guilford.

CONFERENCE PRESENTATIONS:

Wolfe, C. D., and Bell, M. A. (2005, April). *Cognitive and emotional control in early childhood*. In M. Gauvain & S. Perez (Chairs), *Putting the pieces together: How social, emotional, and cognitive processes get integrated over the course of development.* Symposium to be presented at the Society for Research in Child Development, Atlanta.

Wolfe, C. D., and Bell, M. A. (2005, April). *Executive functioning in 3½, 4-, and 4½-year-old children.* Poster to be presented at the Society for Research in Child Development, Atlanta.

Bell, M. A., & **Wolfe, C. D.** (2005, April). *The integration of cognition and emotion during infancy and early childhood: Regulatory processes associated with the development of working memory*. In P. Cole (chair), *Emotion regulation*. Invited symposium for the Society for Research in Child Development, Atlanta.

Bell, M.A., & **Wolfe, C. D.** (2004, July*). Infant predictors of individual differences in working memory during childhood.* Poster presented at the American Psychological Association, Honolulu.

Bell, M.A., & **Wolfe, C.D**. (2004, May). *Using EEG and ECG to investigate the integration of temperament and cognition.* In K.A. Buss (Chair), *Addressing individual differences in temperament and related behaviors using multiple physiological measures*. Symposium paper presented at the International Conference on Infant Studies, Chicago.

Wolfe, C. D., & Bell, M. A. (2004, May). *Differential temperament associations found for two versions of a spatial working memory task.* Poster presented at the International Conference for Infant Studies, Chicago.

Wolfe, C. D. (2003, April). *Brain electrical activity associated with working memory and inhibitory control abilities in early childhood.* Poster presented at the biennial meeting of the Society for Research in Child Development, Tampa.

Wolfe, C. D. (2003, April). *Cognitive inhibitory control, temperament, and language receptivity in early childhood.* Poster presented at the Society for Research in Child Development, Tampa.

Bell, M.A., & **Wolfe, C. D.** (2002, October). *6-9 Hz EEG synchronization during cognitive processing at 8 months and 4 years.* Poster presented at the Society for Psychophysiological Research, Washington DC.

Wolfe, C. D., & Bell, M. A. (2002, April). *Temperament and inhibitory control: infancy to four years of age.* Poster presented at the biennial meeting of the International Conference on Infant Studies, Toronto.

Zachary, L., **Wolfe, C.** & Bell, M. A. (2001, July). *Working memory, inhibitory control, and language in adulthood.* Poster presented at the annual research meeting of the Virginia Tech Minority Academic and Orientation Program, Blacksburg.

Wolfe, C. D., & Zinser, O. (2001, March). *Male coercive sexual behavior as a function of target male resource-potential and respondent gender.* Poster presented at the annual meeting of the Southeastern Psychological Association Regional Conference, Atlanta.

Wolfe, C. D., & Zinser, O. (2000, March). *College student perceptions of male sexual assertiveness: the role of alcohol and relationship longevity.* Poster presented at the annual meeting of the Southeastern Psychological Association Regional Conference, New Orleans.

Orso, M., Hale, C., Benson, T., McCarley, J., & **Wolfe, C. D.** (1999, March). *Psychology in the new millennium: Where your degree will take you.* Symposium conducted at the annual meeting of the Southeastern Psychological Association Regional Conference, Savannah.

Bolinskey, P. K., Rutherford, A. L., **Wolfe, C. D**., & Mangan, P.A. (1997). *The slowing of an internal clock leads to altered time perception in elderly humans.* Poster presented at the annual meeting of the Society for Neuroscience Conference, Washington, DC.

Wolfe, C., Mangan, P. A., Starnes, C., & Atwell, T. (1996, March). The effects of room geometry on children's search behavior. Paper presented at the Southeastern Psychological Association Regional Conference, Norfolk, VA.

TEACHING EXPERIENCE:

Theories of Personality (fall 1999)
Introductory Psychology Guest Lecturer (spring 1999)
Introduction to Psychology Recitation (fall 2000, spring 2001)
Advanced Developmental Psychology Lab (summer 2001, fall 2001, spring 2002)
Advanced Developmental Psychology – Infant/Child Focused (summer 2002, summer 2003)
Developmental Psychology – Life Span Approach (fall 2002, spring 2003)
Cognitive Psychology (summer 2004)

HONORS AND AWARDS:

Virginia Tech Graduate Student Teaching Excellence Award (2004-2005)
American Psychological Association Dissertation Award (2004-2005)
Virginia Tech nominee for the APA Division 7 Outstanding Dissertation Award (2004-2005)
Virginia Tech Psychology Department Galper Fund Award (2004)
Virginia Tech nominee for APF/COGDOP Graduate Research Scholarships in Psychology (2004)
Virginia Tech Graduate Student Association Travel Award (2002, 2003, 2004)
Virginia Tech Graduate Student Annual Evaluation Notable Commendation for Research (2003)
Virginia Tech Graduate Research Development Project Award (2003)
Virginia Tech nominee for APF/Koppitz Graduate Fellowships in Psychology of the Child (2003)

PROFESSIONAL MEMBERSHIPS:

American Psychological Association (since 2004)
International Society for Infant Studies (since 2001)
Society for Research in Child Development (since 2001)
Southeastern Psychological Association (since 1996)

SERVICE:

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