COGNITIVE DEVELOPMENT IN LATE CHILDHOOD:

AN EXAMINATION OF WORKING MEMORY AND INHIBITORY CONTROL

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(ABSTRACT)

An interactive framework of working memory and inhibitory control has been endorsed for examining cognitive development across the lifespan (Roberts & Pennington, 1996). According to this framework, the interaction between working memory and inhibitory control (WMIC) is necessary for adaptive daily functioning (Roberts & Pennington, 1996) and crucial for the development of executive functioning in childhood (Brocki & Bohlin, 2004). Empirical work from early developmental periods supports the interactive WMIC framework (e.g., Bell, 2001; Diamond, Kirkham, & Amso, 2002) and has identified sources of variability (brain electrical activity, temperament, and language) associated with WMIC functioning in infancy and early childhood (Wolfe & Bell, 2004).

Although there is some evidence to suggest the interdependent nature of working memory and inhibitory control in late childhood and adulthood (Diamond, 2002; Luna, Garver, Urban, Lazar, & Sweeney, 2004), work in these later developmental periods has focused primarily on the independent processes of working memory (WM) and inhibitory control (IC) and the interactive WMIC framework has not been directly investigated from late childhood onward. Therefore, the first goal of the current study was to examine the interactive framework in a late childhood sample. The second goal of the study was to examine sources of variability in WMIC functioning in late childhood, with the intention of determining which sources of variability were associated with and contributed unique variance in explaining WMIC performance.

Thirty-eight children (19 male) completed four age-appropriate interactive WMIC tasks (the color-word Stroop, the Fruit Stroop, the counting go/no-go and the Wisconsin Card Sort Test) and two language tasks. Both parents and children responded to a temperament questionnaire. Brain electrical activity was collected via EEG recordings during a two-minute baseline and WMIC tasks.

The four interactive WMIC tasks were tested for relation of the independent (WM, IC) and combined (WMIC) components within tasks and across tasks. The four WMIC tasks were not correlated with one another. However, the independent (WM, IC) components were correlated both with one another and with the combined WMIC measure within each task, providing some support for an interactive framework in late childhood. The sources of variability associated with the independent (WM, IC) and combined (WMIC) components of each task were identified. These sources were used to explain both collective and unique variance in WMIC functioning for each task. Different sources of variability explained independent (WM, IC) and combined (WMIC) performance across tasks. Unique and shared contributors within and across tasks (the color-word Stroop, the Fruit Stroop, the counting go/no-go and the Wisconsin Card Sort Test) and components (WM, IC, WMIC) are discussed in an effort to determine how sources of variability may be related to WMIC functioning.

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Dedication

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Introduction

Cognitive Development in Late Childhood: An Examination of Working Memory and Inhibitory Control

Working memory and inhibitory control are executive function skills associated with frontal lobe functioning (e.g., Carpenter, Just, & Reichle, 2000; Konishi, Nakajima, Uchida, Kikyo, Kameyama, & Miyashita, et al., 1999). Recent theoretical work suggests that the interaction of these processes is critical for daily adaptive functioning (Roberts & Pennington, 1996) as well as the development of executive functioning in childhood (Barkley 1997a, b; Brocki & Bohlin, 2004). Theoretical and empirical work in developmental cognitive neuroscience supports an interactive framework for working memory and inhibitory control (WMIC) in infancy and the early childhood years (e.g., Diamond, 1991, 2002; Bell, 2001; Wolfe & Bell, 2004). However, despite sound theoretical work suggesting lifespan developmental application of the interactive WMIC framework (e.g., Diamond, 2002; Roberts & Pennington, 1996), it has only been investigated in one study from mid-to-late childhood onward (Bell, Wolfe, & Adkins, in press). Therefore, the purpose of the current study was to examine WMIC functioning in late childhood using an interactive framework. In order to discuss the interactive framework, it is necessary to first briefly address its individual components.

Working Memory

According to Baddeley (1996), working memory refers to a limited-capacity system which stores and manipulates transient information online. Working memory differs from long-term memory in its transient, limited-capacity nature and from short-term memory due to its computational and prospective aspects. There are four principal subcomponents of working memory: the phonological loop, the visuo-spatial sketchpad, the central executive and the episodic buffer (Baddeley, 2000). The phonological loop is a temporary storage system where speech-based, acoustic information can be stored and manipulated for indefinite periods with the use of subvocal rehearsal. The visuospatial sketchpad, on the other hand, is responsible for briefly storing and manipulating visual and spatial information. Collectively, the phonological loop and visuospatial sketchpad are referred to as slave systems. The central executive is an attentional control system thought to oversee the slave systems as well as the episodic buffer. The episodic buffer acts as an interface between long-term memory and the slave systems and has the capacity to temporarily store information in a multi-modal code.

Neuroscience studies focused solely on the independent executive function skill of working memory have consistently shown activation in the medial (dorsolateral prefrontal cortex; DLPFC) and lateral frontal regions to be associated with successful working memory performance (Curtis & D'Esposito, 2004; Hong, Lee, Kim, Kim, & Nam, 2000; Petrides, 2000).

More recently, a domain-free, executive-attention based organizational framework of working memory has been presented (Kane & Engle, 2002). This framework can be used to examine individual differences in the domain-specific components of the Baddeley model. Additionally, this model specifically suggests the role of the DLPFC in the active maintenance aspect of working memory (especially in the face of interference), which makes it relevant for the current investigation of the interactive nature of working memory and inhibitory control.

Inhibitory Control

A great deal of the research focusing on inhibitory control addresses the ability to inhibit a prepotent response (e.g., Diamond, Prevor, Callender, & Druin, 1997; Wolfe & Bell, 2004). This is typically referred to as response inhibition and requires *not* performing the dominant response in order to perform a subdominant response. Other work focuses on interference control, which involves inhibiting response to competing, irrelevant information from internal or external sources (e.g., Barkley, 1997a, b). These two forms of inhibition serve to keep an action from occurring or information from interfering with either the task at hand or an upcoming action (Roberts & Pennington, 1996). Cognitive neuroscience studies have associated both interference control and response inhibition with activation of the DLPFC (medial) and orbitofrontal cortices (e.g., Adleman, et al., 2002; Casey, Trainor, Orendi, Schubert, Nystrom, Cohen, et al., 1997; Konishi, et al., 1999; Menon, Adleman, White, Glover, & Reiss, 2001).

An Interactive Framework for Examining Working Memory and Inhibitory Control

Under the interactive framework, it is assumed that working memory and inhibitory control are implicated in a number of everyday tasks, are crucial to normal and adaptive functioning, and should be studied in an interactive fashion (Barkley, 1997 a, b; Brocki & Bohlin, 2004; Roberts & Pennington, 1996). It is specifically suggested that the interaction between working memory and inhibitory control allows for action selection which is necessary in daily activities (Roberts & Pennington, 1996). Finally, it is advocated that the interactive framework should be used to examine normative cognitive development (Roberts & Pennington, 1996).

It has been argued that success on many tasks associated with prefrontal functioning is associated with the ability to act on competing response alternatives, which requires inhibiting the incorrect response and using working memory resources to generate a correct response (Roberts & Pennington, 1996). Theory suggests that when working memory is activated and maintained, certain responses or alternatives are inhibited by default (Goldman-Rakic, 1987; Roberts & Pennington, 1996). However, when inhibitory control demands continue to increase, working memory activations must increase as well to prevent the prepotent response from occurring. This theory is consistent with the argument by Kane and Engle (2002) that associates the combination of the active maintenance component of working memory and interference control with the DLPFC.

Theoretical work on early developmental periods also focuses on the role of the DLPFC in the interaction of working memory and inhibitory control (Diamond, et al., 1997). This interactive framework has been examined and substantiated in empirical work both in infancy (Bell, 2001; Bell, 2005) and early childhood (Diamond, et al., 1997, Wolfe & Bell, 2004). Yet, despite the lifespan applications implied by the theoretical interactive framework, most of the empirical work from mid-to-late childhood and adulthood examines working memory and inhibitory control separately (e.g., Adleman, et al., 2002; Baddeley, 1996; Gathercole, Pickering, Ambridge, & Wearing, 2004; Durston, Thomas, Yang, Ulug, Zimmerman & Casey, 2002). However, a recent meta-analysis suggests that tasks thought to require the interaction of working memory and inhibitory control activate the DLPFC in samples of older children and adults (Diamond, 2002). Therefore, varying levels of empirical and theoretical support for an interactive framework can be found across the lifespan.

In infancy, the A-not-B task is a popular measure of WMIC performance (e.g., Diamond 1990 a,b; Diamond, et al., 1997). In this task, a toy is hidden in one of two identical sites while the infant watches. Following diversion of the infant's attention, s/he is encouraged to search for the toy. After two correct same-side searches, the toy is moved to the alternate site. This task requires the infant to hold in mind where the toy was last hidden (working memory) and avoid reaching back to the location where the toy was hidden previously (inhibitory control). A delay can be initiated between hiding and search to increase task difficulty. Successful task performance has been associated with activation of the medial frontal region (Bell, 2001; Diamond 1990 a,b).

In early childhood, several tasks (including the day-night and yes-no Stroop tasks) have been designed to investigate WMIC (Diamond, et al., 1997; Wolfe & Bell, 2004). These Stroop tasks can be used with children who are not yet reading and require the children to hold two rules in mind (working memory) and inhibit the dominant response to perform the subdominant response. For instance, in the yes-no Stroop task, children are instructed to verbally reply yes when the experimenter shakes his/her head no and to verbally reply no when the experimenter nods his/her head yes. These tasks are thought to be developmentally appropriate assessments of the cognitive processes typically associated with the traditional Stroop. Successful performance on these tasks has also been associated with the medial frontal region (Wolfe & Bell, 2004).

While few studies beyond early childhood *directly* address the interactive WMIC framework, many employ tasks which are suggested to simultaneously require working memory and inhibitory control (WMIC). These tasks include, but are not limited to, the Wisconsin Card Sorting Test (WCST), the traditional Stroop (color-word) task, the Antisaccade task, the Tower of Hanoi, and the counting Go/No-go task (e.g., Mostofsky, Schafer, Abrams, Goldberg, Flower, Boyce, et al., 2003; Roberts & Pennington, 1996; Stroop, 1935). Many of these tasks have been modified, normed, and/or tested for developmental appropriateness with older children (e.g., Heaton & PAR staff, 2003; MacLeod, 1991). Additionally, as discussed below, many of these tasks are associated with DLPFC activation which, according to theory (Kane & Engle, 2002) may reflect the interactive nature of the tasks. Examining findings from studies using tasks with interactive (WMIC) demands may help inform what can be expected in developmental periods where interactive research is disparate or non-existent, particularly late childhood and adulthood.

Two suggested interactive (WMIC) tasks that have been used in behavioral (e.g., Archibald & Kerns, 1999; Levin, Culhane, Hartmann, Evankovich, Mattson, Harward et al., 1991; Welsh, Pennington, & Grossier, 1991) and neuroscience studies (e.g., Adleman, et al., 2002) examining executive functioning in late childhood samples include the WCST and the Stroop task. The WCST requires the individual to use feedback to determine the correct sorting principle (working memory) and to avoid sorting by the same principle when the sorting category changes (inhibition). The Stroop task requires keeping the task rules active and applying them correctly based on the context (working memory) as well as not performing the dominant response of reading the word to perform the subdominant response of naming the color (inhibitory control).

Normative behavioral studies have shown that children in the late childhood range evidence comparable performance on the WCST (Levin, et al., 1991; Welsh, et al., 1991) and traditional Stroop (Christ, White, Mandernach, & Keys, 2001). Cognitive neuroscience work has shown activation of the medial frontal region for both children and adults on the traditional Stroop in fMRI work (Adleman, et al., 2000) and the WCST has become commonly accepted as a measure of prefrontal functioning (Roberts & Pennington, 1996). Performance on a simple go/no-go task, a task typically used to assess inhibition alone, has also been associated with activation of the DLPFC in 7-12 year-olds (Casey, et al., 1997). The authors attribute this activation to working memory demands that may also be required by the task.

Finally, there is one recent behavioral study investigating the development of cognitive processes from late childhood to adulthood, which may provide the greatest support for an interactive WMIC framework in late childhood (Luna, et al., 2004). In an examination of executive function processes, it was found that while many of the processes were independent, working memory and inhibitory control appeared to be both independent and interdependent (using oculomotor tasks; Luna, et al., 2004). Additionally, comparable performance in the late childhood range was observed on the tasks that suggested interdependence of working memory and inhibitory control (WMIC). This finding is consistent with other work in the area of cognitive development which consistently groups children in the late childhood range (10-12 years) based on comparable performance on both working memory tasks and inhibition tasks (Gathercole, et al., 2004; Levin, et al., 1991; Welsh, et al., 1991). Therefore, it appears that age should not be related to WMIC task performance within the late childhood range and that interactive tasks may prove useful in examining individual differences in WMIC functioning.

Finally, adult research in this area may inform research focused on the late childhood period for two main reasons. First, in late childhood, children are evidencing adult-like task performance on many interactive (WMIC) tasks (e.g., Levin, et al., 1991; Welsh, et al., 1991). Second, similarities are seen between children and adults in brain activity associated with these tasks starting shortly before the late childhood period (Casey, Cohen, Jezzard, Turner, Noll, Trainor, et al., 1995; Casey, et al., 1997). For instance, by late childhood, EEG power values are in an adult-like range (Bell, 1998) and frontal brain regions activated on cognitive tasks using fMRI are the same as adults (Adleman, *et al*., 2000; Thomas, King, Franzen, Welsh, Berkowitz, Noll, et al., 1999). Therefore, a brief review of adult studies may help inform what can be expected in late childhood.

In adulthood, it has been theorized that executive (frontal lobe) functions can be interactive and/or independent (e.g., Duncan, Emslie, & Williams, 1996; Duncan, Johnson, Swales & Freer, 1997). This theory was supported in a recent study with adults examining the unity and diversity of executive functions, specifically shifting, working memory and inhibition (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000). Moderate correlations were found between the three functions, which were interpreted as support for both unity and diversity in executive function skills.

In cognitive neuroscience studies with adults, performance on both the traditional Stroop task (Banich, Milham, Atchley, Cohen, Webb, Wszalek, et al., 2000; Bogorodzki, Rogowska, & Yurgelun-Todd, 2005) and WCST (e.g., Berman, Ostrem, Radolph, Gold, Goldberg, Coppola, et al., 1995; Sanz, Molina, Calcedo, Martin-Loeches, & Rubia, 2001) has been associated with activation of the DLPFC attributed to working memory and inhibition demands. DLPFC activation has also been shown to distinguish performance on a simple go/no-go task (thought to tap mainly inhibition) from performance on a counting go/no-go task designed to require both high working memory and high inhibitory control demands (Mostofsky, et al., 2003). In this paradigm, DLPFC activation is only seen in the counting go/no-go task, suggesting that the interactive task requirements recruit this specific area.

Based on the late childhood and adult findings, there is support for investigating the interactive (WMIC) framework beyond early childhood. Considering the findings that working memory and inhibitory control appear to be both independent and interdependent, the current study differed from past work in that it only employed tasks which allowed for delineation of the separate components (WM, IC, WMIC). Examining the interactive framework in the late childhood sample allowed for a comparison of WMIC functioning both across tasks and within tasks. The current study also attempted to extend the interactive framework into late childhood by investigating individual differences in WMIC functioning in a late childhood sample.

Sources of Variability in Working Memory and Inhibitory Control (WMIC) Functioning

Although there appears to be some support for the interactive framework in late childhood (Luna, et al., 2004), no studies to date have examined specific sources of variability in WMIC functioning during this period utilizing an interactive (WMIC) framework. Therefore, it is helpful to turn to work with younger populations that specifically addressed an interactive framework to determine what sources may explain variability in WMIC functioning. Previous studies with younger populations have indicated that temperament, language and brain electrical activity are associated with WMIC performance (Bell, 2001; Gerardi-Caulton, 2000; Hughes, 1998; Wolfe & Bell, 2004). Temperament and brain electrical activity in infancy has been shown to be predictive of WMIC group membership with 88.4% accuracy (Bell, 2005). In preschool children, the three sources of variability predicted WMIC group membership with 90% accuracy (Wolfe & Bell, 2004). Work examining the relation of these factors to the independent processes of working memory and inhibitory control will be examined in the following section to address their applicability to late childhood.

Brain Electrical Activity. Electrophysiological research examining the interactive framework in infancy and early childhood has demonstrated associations between WMIC task success and activation of the DLPFC (e.g., Bell, 2005; Wolfe & Bell, 2004). Studies with late childhood and adult samples, however, have focused primarily on examining the development of executive functions separately as opposed to applying an interactive framework (e.g., Archibald & Kerns, 1999; Casey, et al., 1995; Casey, et al., 1997; Luna, et al., 2004). However, studies employing suggested interactive tasks (e.g., WCST, the color-word Stroop, go/no-go task) in late childhood and adulthood have found medial frontal (DLPFC), lateral frontal, and orbitofrontal activation to be implicated in task success (Adleman, et al., 2002; Casey, et al., 1997; Filley, Young, Reardon, & Wilkening, 1999). As noted previously, DLPFC activation has been associated with both working memory (Casey, et al., 1995; Curtis & D'Esposito, 2004; Hong, et al., 2000; Petrides, 2000) and inhibitory control (e.g., Adleman, et al., 2002; Casey, et al., 1997; Konishi, et al., 1999; Menon, Adleman, White, Glover, & Reiss, 2001) independently in later development. Therefore, it is difficult to discern whether DLPFC activation is related to working memory, inhibitory control or combined WMIC performance in late childhood and adulthood. According to theory (Diamond, 2002; Kane & Engle, 2002), it is the interactive requirements which recruit the DLPFC across the lifespan. In a recent review, it is noted that several aspects of memory (e.g., recognizing or recalling information, maintaining information online) activate the prefrontal cortex (Diamond, 2002), but that it is specifically the ability to maintain information online *while* exercising inhibition (WMIC) that appears to be linked with DLPFC activation.

Different reports of regional activation on interactive tasks in late childhood and adulthood may stem from the fact that the interactive framework has not been directly examined, so the studies cited have focused on different variables of interest based on the unique goals of the specific study. It may also be useful to note that the interactive (WMIC) tasks discussed vary in strength with respect to working memory and inhibition demands. Therefore, the areas implicated in addition to the DLPFC may vary by weight of the independent inhibition and working memory demands required by the specific task. Based on this, a battery of interactive tasks which varied in the strength of the specific task demands were administered to a late childhood sample in the current study. As mentioned, only interactive tasks which allowed for delineation of the independent (WM, IC) and combined components (WMIC) were employed in the current study. This should aid in determining how EEG activation patterns are related to WMIC functioning. It was specifically hypothesized that medial frontal (DLPFC) activation would be implicated in successful WMIC performance on all tasks.

Finally, in regards to differences in brain electrical activity associated with WMIC functioning, previous studies with younger samples have shown an increase in baseline-to-task activation in the 6-9 Hz frequency band associated with interactive WMIC task success. This holds true for infants succeeding on the A-not-B task (Bell, 2001) and preschoolers succeeding on Stroop-like tasks (Wolfe & Bell, 2004). In infancy, an increase in baseline-to-task activation in multiple regions is associated with task success, whereas no change from baseline-to-task is associated with less developed working memory and inhibitory control skills (Bell, 2001, 2002). By age 4 ½, however, an increase in baseline-to-task activation associated with task success has been found only in the medial frontal region (Wolfe & Bell, 2004).

To examine similar changes in the current late childhood sample, a different frequency band was utilized because brain electrical activity at this age shows more adult-like EEG patterns (Bell, 1998). The 8-13 Hz frequency band, known as alpha in adult electrophysiological work, has been associated with cognitive processing in adults (Hugdahl, 1995) and shows the most activity in older children and adults. Specifically, alpha suppression (decreased alpha power values) during task performance is considered indicative of increased activation in the region associated with the scalp location where recording is taking place. Based on this, a decrease in alpha activity from baseline-to-task in the medial frontal region was expected to be associated with successful WMIC performance on all tasks.

Temperament. Temperament is defined as constitutionally based individual differences in reactivity and self-regulation, which are influenced over time by heredity, maturation, and experience (Rothbart & Derryberry, 1981; Rothbart, Derryberry, & Hershey, 2000). Although temperament was initially believed to be present early in life and remain stable over the course of development, it is now agreed that temperament systems follow a developmental course (Rothbart & Jones, 1999). Across development, individual differences in the sensitivity of the reactive and regulatory systems are thought to produce temperamental variability. Research adopting this definition of temperament has shown that individual differences in temperamental reactivity (Gerardi-Caulton, 2000; Rothbart, 1989) and regulation (Derryberry & Rothbart, 1988; Gerardi-Caulton, 2000) influence cognitive processing.

Past work has specifically shown the *regulatory* and *surgent* dimensions of temperament to be related to WMIC functioning in preschoolers (e.g., Wolfe & Bell, 2004). The self-regulatory temperament trait is labeled *effortful control*. Effortful control is defined as the ability to inhibit a dominant response to perform a subdominant response (Rothbart & Bates, 1998). This definition of effortful control is conceptually similar to that of response inhibition and is speculated to be related to cognitive inhibitory control (Davis, Bruce, & Gunnar, 2002; Bell & Wolfe, 2004) because the two share a similar developmental time course and possibly common underlying neural correlates in the prefrontal cortex (Posner & Rothbart, 2000). On the Early Adolescent Temperament Questionnaire- Revised (EATQ-R), which has been specifically normed for 9-16 year-olds, inhibitory control (i.e., the capacity to plan and suppress inappropriate responses), attention (i.e., the capacity to focus attention as well as to shift attention when desired), and activation control (i.e., the capacity to perform an action when there is a strong tendency to avoid it) are included as sub-dimensions of effortful control (Ellis & Rothbart, 2001).

Barkley (1997b) suggests that regulatory abilities are necessary for adaptive executive function skills, including working memory and inhibitory control. Support for this is evidenced in empirical work where effortful control has been associated with cognitive processing. For instance, in early childhood, it has been shown that less negative emotional reactivity and greater effortful control (inhibitory control, focused attention, low-intensity pleasure and perceptual sensitivity) are positively related to conflict resolution (Gerardi-Caulton, 2000) and executive function skills (Wolfe & Bell, 2004). Similar findings are revealed in middle childhood, where effortful control is related to school success (Blair, 2003; Rothbart & Jones, 1999). Additionally, recent work in our lab investigating the relation between WMIC functioning and temperament in 25 8-year-olds has shown self-reported effortful control to be positively correlated with WMIC performance (Bell, Wolfe, & Adkins, in press).

The other dimension of temperament that has been related to WMIC performance is surgency. Surgency has been defined as extraversion (Rothbart & Jones, 1999). High intensity pleasure (i.e., the pleasure derived from activities involving high intensity or novelty), low levels of shyness (i.e., behavioral inhibition to novelty and challenge, especially social), and low levels of fear (i.e., unpleasant affect related to anticipation of distress) make up the surgent dimension of temperament (Ellis & Rothbart, 2001).

In empirical work, the surgent dimension of temperament in early childhood (approach-anticipation) has been found to be negatively related to WMIC performance (Wolfe & Bell, 2004). The surgent dimension of temperament has also been negatively related to academic performance in school-aged children, such that low levels of fear and shyness paired with high levels of intensity pleasure are indicative of lower grades and social problems (Rothbart & Jones, 1999). It is speculated that the child misses relevant information because s/he is easily excited, distracted and often impulsive. The characteristics of a surgent temperament are often paired with low attentional control (Rothbart & Jones, 1999) and map onto the behavioral problems presented by children with ADHD (Barkley, 1997b). In fact, while Barkley (1997b) does not specifically mention temperament, he notes that there is a reciprocal relationship between regulatory abilities (e.g., behavioral inhibition) and executive functions in children with ADHD and their normative comparisons. This complements normative work by Wolfe and Bell (2004) where preschool children rated low on approach-anticipation in parent reports performed higher on WMIC tasks.

In general, there is concern that developmentalists have done little to examine temperament and personality traits in middle and late childhood, ignoring an excellent opportunity to better understand individual development in these periods (Shiner, 1998). Based on the conceptual and empirical work reviewed (e.g., Barkley, 1997, a,b; Rothbart & Jones, 1999), it can be speculated that temperament traits may be related to cognitive processing in late childhood as well. To examine this, the relation between the effortful control and surgency temperament characteristics and WMIC functioning in late childhood were examined in the current study.

Language. Language abilities have been linked to executive functions in normative and non-normative samples (Hoff, 2001; McCauley, 2001), specifically working memory (Baddeley, 2003; Gathercole & Baddeley, 1993) and inhibitory control (Baldwin & Moses, 1996). The development of language has been speculated as a link between effortful control and cognitive inhibitory control (Rothbart, 1989; Ruff & Rothbart, 1996; Wolfe & Bell, 2004). Private speech, in particular, has been implicated in inhibitory control and attentional focusing (Berk, 1992; Bronson, 2000). It is suggested that language is an important self-regulatory ability because of its relation to effortful control (Kopp, 1989; Landry, Miller, Smith, & Swank, 2002).

Research suggests that private speech (self-directed overt or covert speech) is fundamental to all forms of self-regulation (Berk, 1992). Empirical evidence to support this demonstrates that children who use private speech persist longer on tasks and engage in more verbal strategy use (e.g. labeling, rehearsal), thus increasing their success on cognitive tasks (Winsler, Diaz, Atencio, McCarthy, & Adams, 2000). Additionally, private subvocal speech associated with the phonological loop is necessary for holding information online in working memory (Baddeley, 1996; Barkley, 2000) and may be important for the attentional component of working memory that is associated with the DLPFC. Work with children suggests that use of the subvocal rehearsal does not appear until around 7 years of age (Gathercole & Hitch, 1993) at which point it can be used for subvocal rehearsal allowing information to be held in mind longer. This complements the suggestion by Diamond (2002) that the DLPFC is implicated in the integration of working memory and inhibition in school-aged children. Recent work in our lab investigating the relation between language expressivity and WMIC functioning in 25 eight-year-olds found a significant positive correlation between scores on an Expressive Vocabulary Test (EVT; Williams, 1997) and performance on a WMIC measure (Bell, Wolfe, & Adkins, in press).

Language comprehension has also been linked to cognition, specifically WMIC functioning (Wolfe & Bell, 2004). In this study, children who performed well on the Peabody Picture Vocabulary

Test (PPVT-III; a measure of language receptivity) also evidenced successful performance on WMIC tasks. It is suggested that higher language comprehension allows for greater understanding of the task instructions. In other work, it has been shown that children with poor language comprehension score significantly lower than their counterparts on working memory tasks (Nation, Adams, Bowyer-Crane, & Snowling, 1999). Indeed, language comprehension has been indicated as the strongest predictor of WMIC functioning in a normative sample of preschoolers (Wolfe & Bell, 2004). Based on these findings, it is suggested that strengths and weaknesses in basic language skills may be reflected in WMIC functioning. The current study examined the relation between language (receptivity and expressivity) and WMIC functioning in a late childhood sample.

Collective Contributions to Working Memory and Inhibitory Control Functioning

In early childhood, brain electrical activity, temperament, and language collectively explained 90% of variance in WMIC functioning (Wolfe & Bell, 2004). It was hypothesized that the same three factors should contribute to WMIC functioning in late childhood as well. Correlations were used to determine which factors were associated with WMIC functioning. Regression analyses were employed to investigate the collective variance explained by the contributors, as well as to determine which factor appeared to be the strongest contributor in explaining WMIC performance. Finally, additional analyses were undertaken in an attempt to discern how the sources of variability were related to WMIC functioning.

Goals and Hypotheses

There were two main goals of the current study. The first was to examine the interactive framework in late childhood. Only tasks consisting of separable independent (WM, IC) and combined (WMIC) measures were employed in the current study. Therefore, relations among WMIC performance on the four tasks would support the interactive framework. Additionally, relations between the independent (WM, IC) factors within each task and between the independent (WM, IC) and combined (WMIC) factors of each task would support the interactive framework.

The second goal of the current study was to examine sources of variability in WMIC functioning in late childhood including EEG, temperament and language in an effort to understand which factors were related to WMIC functioning and how each factor was related to WMIC functioning. Specific hypotheses for each factor are discussed.

Age. 1) It was hypothesized that age would not be correlated with WMIC performance. Age would only be considered in later analyses if this hypothesis is not supported.

Brain Electrical Activity Hypotheses. 1) Changes in EEG activation in the medial frontal region from baseline to WMIC task were hypothesized to be associated with successful WMIC performance. 2) Additional frontal activation specific to independent working memory (lateral frontal) and inhibitory control (orbitofrontal) performance was investigated.

Temperament Hypotheses. 1) The regulatory dimension of temperament (effortful control) was hypothesized to be positively correlated with WMIC functioning. 2) The surgent dimension of temperament was hypothesized to be negatively correlated with WMIC functioning.

Language Hypotheses. 1) Language receptivity (as measured by PPVT-III scores) was hypothesized to be positively correlated with WMIC functioning. 2) Language expressivity (as measured by EVT scores) was hypothesized to be positively correlated with WMIC functioning.

Collective Contributions. Finally, it was hypothesized that medial frontal EEG, temperament (effortful control and surgency dimensions), and language (receptivity and expressivity) would collectively explain performance on WMIC tasks during childhood. The collective variance of the group of contributors, as well as the unique variance associated with each contributor, was examined. Additional analyses were undertaken to determine how the sources of variability were related to WMIC functioning.

Method

Participants

Forty children (20 male), aged 9-12 years (M = 11.12), and their parents were recruited for participation in this study. Families were recruited using two methods: the Developmental Sciences Database and a campus notice on the Virginia Tech homepage (see Appendix A). Families from the

Developmental Science Database with children in this age range received a recruitment letter (see Appendix B) notifying them of the purpose of the current study and alerting them of a follow-up phone call to assess interest in participation. Approximately one week after sending the recruitment letters, follow-up phone calls were placed to assess interest, answer questions, and schedule appointments for families willing to participate. Families recruited through the campus notice placed on the Virginia Tech homepage contacted the experimenter by email or phone. The information in the recruitment letter was shared with the parent and an appointment was scheduled if the family was interested and the child was eligible. Children received a $10 gift card to Books-a-Million as compensation for their participation.

Participants were predominantly Caucasian, with the minimum parent education level being high school completion. Complete data were available for 38 participants (19 male). EEG data were lost for one participant due to experimenter error and another participant was dropped following disclosure by the parent that the child had been diagnosed with Speech and Language Impairment (SLI).

Procedures

Children and parents came to the Developmental Cognitive Neuroscience Lab located in Williams Hall for a one-time visit that lasted approximately one hour. Upon arrival, children and their parents were greeted, procedures were reviewed, and parental consent (see Appendix C) and child assent (see Appendix D) were obtained. The parent was escorted to the control room where s/he could see and hear the session, but would not serve as a distraction to the child. The child was seated at a small table in an adjustable chair. S/he responded to a temperament questionnaire administered by a research assistant while the EEG cap was applied. Then, s/he participated in four cognitive tasks and two language tasks. Physiological and behavioral measures used are described below.

Questionnaires

The parent completed two questionnaires while s/he waited in the control room. The child completed one questionnaire with the assistance of a research assistant.

EATQ-R Parent Report. The parent form of the Early Adolescent Temperament Questionnaire-Revised (EATQ-R; Ellis & Rothbart, 1999) was used to examine parental perceptions of child temperament as well as any relations between these parental perceptions and the children's cognitive skills assessed in this study. The EATQ-R parent version is a 62-item questionnaire designed to measure parent report of general patterns of behavior and temperament (see Appendix E). Four broad temperament factors were yielded from this measure (Rothbart & Ellis, 2001): effortful control (activation control α = .66, inhibitory control, α = .86, and attention α = .65), surgency (high intensity pleasure α = .70, low shyness α = .72, and low fear α = .69), affiliativeness (affiliation α = .82), and negative affectivity (frustration α = .74, depressive mood α = .76, aggression α = . 71). Two behavioral scales were derived from the measure: aggression (low effortful control, high surgency, and low affiliativeness) and depressive mood (low effortful control, high affiliativeness, and high negative affectivity). Examining the factors of interest, effortful control and surgency, parents rated girls higher on effortful control than boys.

General Information Questionnaire. The parents also completed a general information questionnaire (see Appendix F). Parent age, education level, and information about the child (e.g., handedness, neurological problems, illness, medication use) were reported on this form.

EATQ-R Short Form Child Report. The shortened version of the Early Adolescent Temperament Questionnaire - Revised (EATQ-R; Ellis & Rothbart, 1999; see Appendix G) was used to measure general patterns of behavior and temperament as reported by the child. Self-report of temperament was used in the study to compare child perception of temperament and behavioral style to cognitive performance. Four broad temperament factors were yielded from this measure (Rothbart & Ellis, 2001): effortful control (activation control α = .76, inhibitory control, α = .69, and attention α = .67), surgency (high intensity pleasure α = .71, low shyness α = .82, and low fear α = .65), affiliativeness (affiliation α = .75, perceptual sensitivity α = .71, pleasure sensitivity α = .78), and negative affectivity (frustration α = .70, depressive mood α = .69, aggression α = . 80;). Two behavioral scales were derived from the measure: aggression (low effortful control, high surgency, and low affiliativeness) and depressive mood (low effortful control, high affiliativeness, and high negative affectivity). The parent and child report of the temperament questionnaire have been shown to be positively correlated (Ellis & Rothbart, 2001). The

EATQ-R is a 65-item questionnaire designed for use with children and adolescents, ages 9-16 years. The EATQ-R was administered to the children by a research assistant during application of the EEG cap. Children were read the statements from the questionnaire and responded on a scale from 1 (almost always untrue) - 5 (almost always true) how true the statement was for them. They were instructed to address the research assistant if they needed her to repeat or clarify the statement. An answer guide with both the numbers and written responses was provided for the participant (see Appendix H).

Physiological Measures

During application of the EEG cap, the child responded to the EATQ-R (Ellis & Rothbart, 1999; discussed in detail above). The questionnaire was completed during application of the cap in order to entertain the child and to decrease the length of the session. Prior to the assessment of baseline physiological recordings and task administration, the children were allowed to view their online physiological recordings on the computer monitor. This served to help the children understand how movement creates artifact in the recordings. Then, baseline physiological recordings were assessed. Participants were instructed to sit still and quiet with their eyes open for one minute. This procedure was repeated with their eyes closed. Recordings continued during task WMIC administration.

EEG. EEG was recorded using an ElectroCap from 8 left scalp locations and 8 right scalp locations: frontal pole (F1, F2), 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. Following application of the ElectroCap, NuPrep and EEG Gel conductor were inserted at each recording site and the scalp was abraded gently. Electrode impedances were accepted if they were below 10K ohms (Pivik, Broughton, Coppola, Davidson, Fox, & Nuwer, 1993). The electrical activity for each site was amplified with separate SA Instrumentation Bioamps, bandpassed from 0.1 to 100 Hz and notch filtered at 60 Hz. The data were digitized online at 512 samples per second to prevent aliasing.

Software developed by the James Long Company (Canoga Lake, NY) was used to analyze the EEG data. The data were re-referenced by the software for an average reference configuration. Average referencing was used to weight the electrode sites equally, eliminating the need for a noncephalic reference. Active to reference electrodes vary across the scalp, so the re-referencing was necessary to accurately reflect the electrical potential of each site without interelectrode distance being reflected. Data were artifact scored for eye movements (using F1 and F2 as a guide) and gross motor and muscle movement artifact through visual examination. The artifacted EEG segments were removed from subsequent data analysis. Artifact-free data were then analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-sec width and 50% overlap. Power was computed for the 8-13Hz frequency band based on a review of the ontogeny of EEG during childhood which shows that EEG power values in late childhood are in the adult-like range (Bell, 1998). EEG power was expressed in mean square microvolts and the data were transformed using the natural log (ln) to normalize the distributions.

Interactive WMIC Tasks

Four tasks requiring the interaction of working memory and inhibitory control were administered. Tasks included the color-word Stroop, a non-reading Stroop-like task (fruit Stroop), the counting go/no-go task (adapted from Mostofsky, et al., 2003), and the 64 card computerized version of the Wisconsin Card Sorting Test (WCST-64; Heaton & PAR staff, 2003). The tasks were chosen to vary in strength of working memory and inhibitory control demands and for the ability to delineate the separate components (working memory, inhibitory control, WMIC; see Table 1). EEG was recorded during all four tasks. Because all participants participated in all tasks, the tasks were counterbalanced using a Latin-square design (Campbell & Stanley, 1963; see Appendix I).

Color-word Stroop The color-word Stroop task requires high inhibitory control demand and low working memory demand (Roberts & Pennington, 1996). The Stroop task has many variations (see MacLeod, 1991 for review). The color-word Stroop, which was employed in the current study, has been associated with activation of the DLPFC attributed to working memory (Banich, et al., 2000) and inhibitory control (Bogorodzki, et al., 2005) demands.

Previous developmental work with participants in the late childhood range has used the Golden Stroop version (Golden, 1978) of the color-word Stroop task (Adleman, et al., 2002; Archibald & Kerns, 1999), which was employed here. Participants were presented with three sub-tests (see Figure 1). In each subtest, the participant was presented with a page of 10 rows consisting of 5 items per row (modified from Archibald & Kerns, 1999 and Slaats-Willemse, Swaab-Barneveld, Sonneville, Meulen, & Buitelaar, 2003). For all subtests, the participants were told they had 45 seconds to read/name as many items as possible, correcting any mistakes and continuing. They were instructed to start over with the first row if they completed the entire page under the 45 second time limit. In the first sub-test, the participant was presented with a page of color words (i.e., blue, red, green, yellow) printed in black ink. The participant was instructed to read the words from left to right. Secondly, the participants were presented with XXXX's varying in ink color. They were instructed to name the color of the ink for each XXXX set. Lastly, the participants were presented with color words printed in an incongruent ink color (i.e., red, blue). Participants were instructed not to read the word, but to name the ink color instead.

The working memory task demand for this task required that the participants maintain the rules online and apply them to the current context (Roberts & Pennington, 1996). The inhibitory control demand, naming the color instead of reading the word in the incongruent condition, is assumed to be required after reading becomes automated (Hanauer & Brooks, 2005; MacLeod, 1991). Interference for this task is thought to be maximal in Grades 2 and 3 (Comalli, Wapner, & Werner, 1962).

Raw scores were determined for each subset (word, color, color-word) by calculating the number of items completed in the 45 second interval. An interference score was calculated based on the difference of actual performance on the color-word task (raw color-word score) minus predicted performance on the color-word task [(raw word score * raw color score)/(raw word score + raw color score); Adleman, et al., 2002)]. Inhibition of the prepotent response is reflected by the interference score (Slaats-Willemse, et al., 2005), which was based on the total number of items the participant completed in the 45 second interval (Archibald & Kerns, 1999). Therefore, the *total-completed* interference score served as a measure of inhibitory control.

Correct responding in the incongruent color-word condition required active maintenance and application of the rules to name the ink color and ignore the word, which is reflective of working memory

(Roberts & Pennington, 1996). Therefore, the number of correct responses in the incongruent color-word sub-test was used as a measure of working memory.

Interference control is the measure most often cited in studies that find a significant correlation between working memory and inhibitory control (e.g., Koch, 2001). Typically, these studies have based the interference score on the total number of *correct* items as opposed to the total number of completed items. Studies that find DLPFC activation associated with the Stroop (which they attribute to working memory demands associated with the task) report interference control as their behavioral measure (e.g., Banich, et al., 2000). Therefore, an *error-based* interference score based on total correct served as the WMIC measure for this task.

The Fruit Stroop. This task was used as an ecologically valid, developmentally appropriate, non-reading version of the Stroop task (Archibald and Kerns, 1999). To date, there are no publications reporting brain regions associated with this task. Archibald and Kerns (1999) employed the task as a measure of inhibitory control with children aged 7-12 years, but found that it was significantly correlated with three of the four working memory scores reported, suggesting that it may require working memory as well. This task was considered an assessment of low working memory and high inhibitory control because its Stroop-like nature, requirements, and scoring are similar to work using the classic color-word Stroop task.

Each participant was presented with four pages of stimuli in this task (see Figure 2). For each page, the participant was instructed that s/he has 45 seconds to name as many items as possible. For all subtests, the participants were instructed to name the colors as quickly as possible, correcting any mistakes and continuing. In addition, they were instructed to start back at the top of the page if they named all the items listed on the page before time expired. The first page consisted of colored rectangles (i.e., blue, yellow). The participant was instructed to name the color of each rectangle. The second page consisted of appropriately colored fruit (i.e., yellow bananas, red apples). The participants were instructed to name the color of each fruit. The third page was the same as the second page with the exception that the fruit was presented in gray scale. The participant was instructed to name the correct fruit color based on the previous page. The final page presented the fruit in the same order as the previous two pages only in an incongruent color (i.e., green bananas, yellow grapes). The participant was again instructed to name the correct fruit color.

The dependent measures derived from the fruit Stroop were modeled after the color-word Stroop as both are high in inhibitory control. Raw scores (the total number of items completed in allotted time) were calculated for each subtest. The total number of correct items served as the working memory index. An interference score was calculated by subtracting the predicted score [(rectangles * grayscale fruit)/(rectangles + grayscale fruit)] from the actual score (incongruent fruit). Scoring the task based on the number of items completed in the allotted time is thought to be a developmentally appropriate and sensitive index of inhibition performance (Archibald & Kerns, 1999), so this total-completed interference score was used as the inhibitory control measure. Finally, an error-based interference score was used as the interactive WMIC score.

Counting Go/No-Go Task. The counting go-no task, modified from Mostofsky, et al. (2003), was used to assess WMIC performance. This task is considered to be high in both working memory and inhibitory control demands. In adult fMRI work, the counting go/no-go task has been found to activate the DLPFC (Mostofsky, et al., 2003). In the current study, a modified version of the task was used.

The task was presented to participants on a Windows 2000 laptop. Participants were told they were going to rescue spaceships by pressing the space bar. They were instructed to rescue all green spaceships and red spaceships following an even number of green spaceships. Therefore, they were not supposed to respond to red spaceships following an odd number of green spaceships. This required participants to remember the rules and constantly update information (the number of green ships presented since the last red spaceship), thus taxing working memory. In addition, the participants were required <u>not</u> to respond to red spaceships following an odd number of green spaceships placing demands on inhibitory control. To ensure the task required high inhibitory control, approximately 89% of the stimuli presentations required a rescue response (79% green spaceships; 10-11% red spaceships following an even number of green spaceships). In addition, this task is thought to be more difficult because it is ecologically valid in that green is typically associated with a go response and red with a stop response.

The task began with a practice session with two even and two odd red spaceship presentation trials to ensure that the participants understood the rules of the task. The practice session was then followed by a lengthier test block. The participants were reminded of the rules prior to the onset of the testing block. In both the practice and test block, each spaceship appeared in the middle of the screen, marked by a fixation point, for a duration of 400 milliseconds (ms). This was modified from 200 ms in the adult study to give the children more time to process the stimuli. Minimum response time was also extended from 1300 ms to 1600 ms (see Figure 3). Based on attentional work (Rueda, Fan, McCandliss, Halparin, Gruber, Lericari, & Posner, 2004), children in this age range were allowed less than 1700 ms to respond to a visual stimulus. In other work, Archibald and Kerns (1999) presented one stimulus per second in a simple go/no-go task used with children 7-12 years of age, whereas Levin, et al. (1991) presented stimuli for three seconds apiece. Combining the 400 ms display and the 1600 ms response time allowance, participants were presented with one stimulus every two seconds.

Omission errors (not responding to a go response) and commission errors (failing to inhibit a no-go response) were calculated. In a previous study with this age group, omission errors were indicative of working memory performance, whereas commission errors were indicative of response inhibition (Archibald & Kerns, 1999). Total items correct on the task served as the measure of WMIC functioning as it accounts for both omission (working memory) and commission (inhibitory control) errors.

Computerized 64-card Wisconsin Card Sorting Test. The original WCST is well accepted in the literature as a measure of frontal lobe functioning for children and adults (e.g., Barcelo, Sanz, Molina, & Rubia, 1997; Levin, et al., 1991; Stuss & Benson, 1986). Successful performance on the WCST has specifically been attributed to working memory and inhibition demands associated with the DLPFC (e.g., Berman, et al., 1995; Sanz, et al., 2001). This task is considered to be high in working memory demands and low on inhibitory control demands (Roberts & Pennington, 1996).

The 2nd edition of the 64-card computerized version of the WCST was used in the proposed study (WCST-64; Heaton & PAR staff, 2003). The WCST-64 has the advantage of shortened administration time with retention of the original task demands. Participants viewed four key cards across the top of the computer screen (see Figure 4). They were instructed to match a stimulus card, which appeared at the bottom of the screen, to one of the four key cards located the top of the screen. No details concerning the sorting principles were shared with the participant who simply had to click on the card s/he believed was a match. The computer provided feedback, responding with a written "right" or "wrong" display. The participant was inhibited from responding during the time the feedback was displayed on the screen. Following every ten consecutive correct responses, the matching criteria automatically changed. This process continues until all 64 cards were sorted.

Difficulty in remembering previous and concurrent correct and incorrect responses and manipulating them to guide future sorting, associated with the working memory demand of the task, is thought to lead to default (previously correct, but currently incorrect) responses (Roberts & Pennington, 1996). Conceptual level responses (consecutive correct responses occurring in runs of three or more) reflect insight into and maintenance of the current sorting strategy (Heaton & PAR staff, 2003). Conceptual level responses were used in the current study as the working memory measure for the WCST. Inhibitory control was assessed by perservative errors, which are reflective of the inability to inhibit a learned strategy, on the WCST (Bull & Screif, 2001). Lower inhibitory control is seen in prepotent responding, continuing to sort by the previously correct category, as opposed to using the feedback and attempting to sort by a new category. Initial performance is thought to be superior to later performance on this task because prepotent responding becomes stronger with increasing trials (Roberts & Pennington, 1996). The inhibitory control demands of the WCST task were considered low because the duration between responses was untimed making the prepotent response weaker (Roberts & Pennington, 1996). Mandatory time between responses (when the card moves to the correct pile) was decreased as much as possible to increase inhibitory control requirements. Finally, total items correct served as the measure of WMIC functioning and the primary variable of interest from the WCST-64 because it accounts for conceptual level responses (working memory) and perservative errors (inhibitory control).

Language Assessments

Peabody Picture Vocabulary Test-III. The Peabody Picture Vocabulary Test- III was administered to measure receptive vocabulary and verbal comprehension (Dunn & Dunn, 1997). The PPVT-III is a nationally standardized instrument. The participant was shown a set of four pictures and read a word. The participant was then asked to point to the picture that best corresponded to the word. A score was obtained by administering the participant the age-appropriate start items and using the basal and ceiling rules.

Expressive Vocabulary Test. The EVT is a test of expressive vocabulary and word retrieval, containing two types of items: labeling and synonyms (Williams, 1997). It has been normed for ages 2-1/2 through 90+ years and co-normed with the PPVT-III. Only the synonym items are administered to children in the late childhood age range. For these items, the examiner presented the participant with a picture and a stimulus word(s). The examinee was told to respond to each item with a one-word answer. Two unscored examples were presented before the section began. As with the PPVT, only items that most closely approximated the ability level of the participant were administered and a score was obtained through the use of age-appropriate start items and basal and ceiling rules.

Results

There were two main goals of this study. The first goal was to examine the interactive framework in the late childhood period. The second goal was to examine possible sources of variability associated with WMIC performance and to determine the collective contribution of these sources in explaining WMIC performance. Means and standard deviations for WMIC task performance indices and investigated sources of variability can be found in Table 2.

Interactive Framework Examination

Four separate tasks, the color-word Stroop, the fruit Stroop, the counting go/no-go, and the WCST, were chosen as WMIC measures. Three series of analyses were undertaken to explore the first goal. First, analyses were undertaken to determine if the four tasks were related, because each of the tasks were hypothesized to differ in the weight of the independent components of working memory and inhibitory control. Second, regressions were used to examine the independent contributions of working memory and inhibitory control to the combined WMIC measure for each task to ensure that the tasks actually differed in weights of the independent components. Finally, analyses were undertaken to examine whether each individual task evidenced the hypothesized relation between working memory and inhibitory control consistent with the interactive framework. Due to the number of tests necessary to examine the goals of the study, a significance level of $p \leq .01$ was adopted in an effort to reduce the probability of Type I error. Although tests with a significance level of $p \leq .05$ are acknowledged in the tables, only the tests with a significance level of $p \leq .01$ will be discussed.

Correlations among tasks. In the first set of analyses, Pearson correlations were utilized to test for relations among the independent (WM, IC) and combined (WMIC) measures of the four tasks. The correlations among the combined measures indicated that the four WMIC tasks were not correlated (see Table 3). Follow-up Pearson correlations among the independent working memory (see Table 4) measures across the four tasks evidenced that only the working memory components of the color-word and fruit Stroop tasks were positively correlated ($r(38) = .51$, $p < .01$). No significant correlations were seen across tasks for the independent inhibitory control (see Table 5) measures. Additionally, Pearson correlations among the independent working memory and inhibitory control components were not correlated *across* tasks (see Table 6).

In the second set of analyses, regressions were used to show that each task differed in the weight of the independent components (WM, IC). Specifically, standardized coefficients (β) were used to examine the relative importance of the independent components of working memory and inhibitory control within each task (Keith, 2006). Regression analyses indicated that the color-word Stroop task was higher in inhibitory control demand than working memory demand ($\beta = .75$, $t = 11.65$, $p < .01$ and $\beta = .27$, $t = 4.21$, $p < .01$, respectively; $R^2 = .93$, $p < .01$ for the model), with both components explaining unique variance in color-word Stroop WMIC performance. Specifically, less total-completed interference (actual score – predicted score, where *higher* scores were equivalent to less interference) and greater numbers of total items correct (working memory) positively influenced color-word WMIC performance, with changes in total-completed interference having the greater impact on WMIC performance.

The fruit Stroop task was also higher in inhibitory control demand than working memory demand ($\beta = .83$, $t = 12.19$, $p < .01$ and $\beta = .19$, $t = 2.82$, $p < .01$, respectively; $R^2 = .88$, $p < .01$ for the model) with both components explaining unique variance in fruit Stroop WMIC performance. Again, less total-completed interference (actual score – predicted score where *higher* scores were equivalent to less interference) and greater numbers of total items correct (working memory) positively influenced WMIC performance, with changes in total-completed interference having the greater impact on fruit Stroop WMIC performance.

Inversely, regression analyses showed that the WCST task was higher in working memory demand than inhibitory control demand ($\beta = .82$, $t = 13.70$, $p < .01$ and $\beta = -.19$, $t = -3.23$, $p < .01$, respectively; $R^2 = .94$, p < .01 for the model), with both components explaining unique variance in WCST WMIC performance. Here, increased conceptual level responses (working memory) and decreased perservative errors positively influenced WMIC performance, with changes in conceptual level responses having the greater impact on WCST WMIC performance.

Finally, the counting-go/no-go task was hypothesized to be high (equivalent) in both working memory and inhibitory control demands, which was supported with a regression analysis ($\beta = -.67$, $t = -62.99$, $p < .01$ and $\beta = -.51$, $t = -48.52$, $p < .01$, respectively; $R^2 = .99$, p < .01 for the model) where both components explained unique variance in counting go/no-go WMIC performance. Specifically, increased omission (working memory) and commission (inhibitory control) errors negatively impacted counting go/no-go WMIC performance.

Correlations within tasks. It was suggested that the four tasks might not be significantly correlated due to the differing weights of the independent components, but that significant correlations between the independent components of working memory and inhibitory control within each task should be seen in order for the task to be considered an age-appropriate WMIC measure. While Pearson correlations did not support the relation among tasks (see above), they did show that the independent measures of working memory and inhibitory control *within* each task were correlated (see Table 7). Positive correlations were observed between the working memory and inhibitory control measures on both Stroop tasks, such that the total number of correct items increased as the amount of total-completed interference decreased (less interference being reflected more positive numbers). A positive correlation was also seen between the independent components (WM, IC) on the counting-go-no task, such that the number of omission errors decreased as the number of commission errors decreased. Finally, a negative correlation was observed between the independent components (WM, IC) of the WCST, where the number of conceptual level responses increased as perservative errors decreased.

Pearson correlations were also used to examine whether the individual independent components (WM, IC) within each task were correlated with the WMIC measure for that same task. While it may seem apparent that the independent components of working memory and inhibitory control would be correlated with the WMIC components within each task, this needed to be tested because WMIC components were not a summative measure of working memory plus inhibitory control for each task, but were separate measures hypothesized to require both components for success. Pearson correlations showed that the working memory measure of each task was correlated with the WMIC score for that task (see 6). For the Stroop tasks, there was a positive correlation between the working memory and WMIC measures, such that the total number of items correct increased as the amount of error-based interference decreased (less interference being reflected by more positive numbers). There was also a positive correlation between the working memory and WMIC measure of the WCST task, such that the number of conceptual level responses increased as the total number of items correct increased. Finally, there was a negative correlation between the working memory and WMIC measures of the counting-go-no task, such that the number of omission errors decreased as the total number of items correct increased.

The same pattern was observed with the inhibitory control measure for each task being correlated with the WMIC score for that task (see Table 8). Here, positive correlations were seen between the inhibitory control and WMIC measures for the Stroop tasks, where the amount of total-completed interference decreased as the amount of error-based interference decreased. Inversely, negative correlations were seen between the inhibitory control and WMIC measures for the counting-go/no-go and WCST tasks. For the counting-go-no task, the number of commission errors decreased as the total number of items correct increased. For the WCST task, the number of perservative errors decreased as the total number of items correct increased.

Sources of Variability

The second goal of the study was to examine possible sources of variability in WMIC performance in late childhood. Based on past work, brain electrical activity, temperament and language were examined as sources of variability in WMIC performance using Pearson correlations and regression analyses in the following section. Because the four tasks were not correlated with one another, all analyses were performed with both the independent (WM, IC) and combined (WMIC) measures for each task in an effort to understand how the hypothesized sources of variability may be related to WMIC performance in late childhood. Pearson correlations were initially used to determine which of the hypothesized sources were related to the independent (WM, IC) and combined (WMIC) measures. Regression analyses were then performed, entering only the sources shown to be significantly related to the given measures in the previous correlations, to determine the relative importance of individual variables for explaining variance in each of the measures.

Age. Past work has suggested that performance on these and similar types of tasks is comparable across late childhood (Christ, et al., 2001; Gathercole, et al., 2004; Levin, et al., 1991 Welsh, et al., 1991). Pearson correlations were undertaken to ensure that this same trend was evident in the current sample. Correlations were computed to examine the relations between age and the independent (WM, IC) and combined (WMIC) scores for each task. Age was not correlated with the combined (WMIC) scores for any of the four tasks (see 3). Age was also not correlated with the independent working memory scores of the four tasks (see Table 4) nor was it correlated with the independent inhibitory control scores of the four tasks (see Table 5). Based on these analyses and their consistency with past work, age was not included as a source of variability in any of the later analyses.

Brain Electrical Activity. Pearson correlations were performed to test for relations between baseline-to-task change at each of the 16 scalp regions and independent (WM, IC) and combined (WMIC) task performance. It was hypothesized that increased alpha activation in the medial frontal region (F3/F4) from baseline-to-task would be associated with higher working memory, inhibitory control and WMIC task performance. Baseline-to-task change was calculated by subtracting task EEG power values from baseline EEG power values.

For the color-word Stroop task, no baseline-to-task changes were associated with independent (WM, IC) or combined (WMIC) task performance (see Table 9).

For the fruit Stroop task, no baseline-to-task changes were associated with independent (WM, IC) or combined (WMIC) task performance (see Table 10).

For the counting go/no-go task, baseline-to-task change at left medial frontal region F3 ($r(38) = -.48$, $p < .01$), right lateral frontal region F8 ($r(38) = -.39$, $p \leq .01$), and bilateral parietal regions P3 ($r(38) = -.49$, $p < .01$) and P4 ($r(38) = -.47$, $p < .01$) were correlated with working memory performance (see Table 11). Baseline-to-task alpha *desynchronization* (decreased power values associated with increased activation) at left medial frontal, right lateral frontal, and bilateral parietal regions was associated with higher scores on the counting go/no-go working memory measure. Alpha desynchronization was evidenced by a positive difference score (baseline EEG power – task EEG power) denoting a decrease in power values from baseline-to-task. A negative correlation was shown between baseline-to-task change and working memory performance on the counting go/no-go task where omission errors decreased as alpha activation (desynchronization as evidenced by positive difference values) increased.

Baseline-to-task change at medial frontal region F3 ($r(38) = .47$, $p < .01$) and parietal regions P3 ($r(38) = .46$, $p < .01$) and P4 ($r(38) = .45$, $p < .01$) were also correlated with WMIC performance on the counting go/no-go task (see Table 11). Alpha desynchronization (decreased power values) at left medial frontal and bilateral parietal sites was associated with performance on the counting go/no-go WMIC measure. A positive correlation was seen between baseline-to-task change and WMIC performance where the total number of items correct on the counting go/no-go increased as alpha activation (desynchronization as evidenced by positive difference values) increased. No baseline-to-task changes were associated with the counting go/no-go inhibitory control measure (see Table 11).

For the WCST task, baseline-to-task change at frontal pole F1 ($r(38) = -.44$, $p \leq .01$) was correlated with working memory performance (see Table 12). Alpha *synchronization* at the left frontal pole was associated with higher scores on the WCST working memory measure. In this instance, an increase in EEG power values was seen from baseline-to-task, leaving a negative difference when the change score was calculated. Therefore, a negative correlation was seen between baseline-to-task change and working memory performance on the WCST where the number of conceptual level responses increased as alpha synchronization (evidenced by negative difference values) increased.

Baseline-to-task change at frontal site F1 ($r(38) = -.39$, $p \leq .01$) was also correlated with WMIC performance on the WCST (see Table 12). Again, greater alpha synchronization (as evidenced by negative difference values) at the left frontal pole was associated with higher scores on the WCST WMIC measure. No baseline-to-task changes were associated with inhibitory control performance on the WCST (see Table 12).

Temperament. It was hypothesized that the effortful control and surgency dimensions of temperament would respectively be positively and negatively correlated with task performance. Pearson correlations were used to examine whether the parent and child temperament factors of effortful control and surgency were related to the independent and combined working memory and inhibitory control scores for each task.

For the color-word Stroop, child report of effortful control was positively correlated with inhibitory control performance ($r(38) = .38$, $p \leq .01$; see Table 14), where total-completed interference decreased (less interference being reflected by more positive numbers) as self-report of effortful control increased. Child report of effortful control was also positively correlated with color-word Stroop WMIC performance ($r(38) = .44$, $p < .01$; see Table 15), where error-based interference decreased (less interference being reflected by more positive numbers) as self-report of effortful control increased. Child report of effortful control was not significantly associated with working memory performance on the color-word Stroop (see Table 13). There was no relation between independent (WM, IC) or combined (WMIC) task performance on the color-word Stroop and parent report of effortful control (see Tables 13-15).

For the fruit Stroop, parent report of effortful control was positively correlated with working memory performance ($r(38) = .38$, $p \leq .01$; see Table 13), where the total number of items correct increased as parent report of effortful control increased. Parent report of effortful control was also positively correlated with fruit Stroop inhibitory control performance ($r(38) = .45$, $p < .01$; see Table 14), where total-completed interference decreased (less interference being reflected by more positive numbers) as parent report of effortful control increased. Finally, parent report of effortful control was positively correlated with fruit Stroop WMIC performance as well ($r(38) = .43$, $p < .01$; see Table 15), where error-based interference decreased (less interference being reflected by more positive numbers) as parent report of effortful control increased. There was no relation between independent (WM, IC) or combined (WMIC) task performance on the fruit Stroop and child report of effortful control (see Tables 13-15).

For the counting go/no-go task, there was no relation between child report of effortful control and independent (WM, IC) or combined (WMIC) task performance (see Tables 13-15). There was also no relation between independent and combined counting go/no-go task performance and parent report of effortful control (see Tables 13-15).

For the WCST task, there was no relation between child report of effortful control and independent (WM, IC) or combined (WMIC) task performance (see Tables 13-15). There was also no relation between independent and combined WCST task performance and parent report of effortful control (see Tables 13-15).

For all four tasks, neither parent nor child report of surgency was related to working memory (see Table 16), inhibitory control (see Table 17) or WMIC (see Table 18) performance.

Parent and child reports of effortful control were positively correlated ($r(38) = .49$, $p < .01$), as were parent and child reports of surgency ($r(38) = .42$, $p < .01$).

Language. It was hypothesized that both language expressivity and receptivity would be positively correlated with task performance. Pearson correlations were calculated between standardized receptive and expressive language scores and task performance on the independent (WM, IC) and combined (WMIC) measures for each task.

For the color-word Stroop, expressive language was correlated with working memory performance ($r(38) = .46$, $p < .01$), such that the total number of items correct on the color-word Stroop increased as standardized scores on the EVT increased. Expressive language was also positively correlated with WMIC performance on the color-word Stroop ($r(38) = .45$, $p < .01$), where error-based interference decreased (as indicated by more positive numbers) as standardized EVT scores increased. No significant relations were found between receptive language and performance on the color-word Stroop (see Tables 19-21) or between expressive language and performance on the color-word Stroop inhibitory control measure (see Table 20).

For the fruit Stroop, no significant relations were found between receptive and expressive language scores and task performance (see Tables 19-21).

For the counting go/no-go task, receptive language was negatively correlated with working memory performance ($r(38) = -.43$, $p < .01$; see Table 19), such that the number of omission errors decreased as the standardized EVT scores increased. Receptive language was also correlated with the counting go/no-go WMIC measure ($r(38) = .41$, $p < .01$; see Table 21), such that the total number of items correct increased as the standardized EVT scores increased. No significant relations were found between expressive language and performance on the counting go/no-go task (see Tables 19-21) or between receptive language and performance on the counting go/no-go inhibitory control measure (see 20).

Collective Contributions. Regressions were used to determine the amount of variance explained by the above sources of variability for each of the independent (WM, IC) and combined (WMIC) measures. A contributor was entered into the regression to determine its strength as a unique source of variance only if it was significantly correlated with task performance on the indicated measure in the above analyses.

For the color-word Stroop task, EVT performance explained 21% of variance in *working memory* performance ($R^2 = .21$, $F(1, 37) = 9.64$, $p < .01$, $\beta = .46$, $t = 3.10$, $p < .01$; see 22). Therefore, increased standardized EVT scores positively influenced working memory performance on the color-word Stroop. Interpreting the beta weight (which uses a standard unit of measurement common to all variables in the equation) evidenced that a .46 unit increase in total items correct was seen with a one unit increase in standardized EVT scores. Child report of effortful control explained 14% of variance in *inhibitory control* performance on the color-word Stroop ($R^2 = .14$, $F(1, 37) = 6.24$, $p \leq .01$, $\beta = .38$, $t = 2.49$, $p \leq .01$; see Table 23). Here, increased self-report of effortful control positively impacted inhibitory control performance, such that a .38 unit increase in total-completed interference scores (with higher scores indicative of less interference) was seen with a one unit increase in reported effortful control scores. Finally, EVT performance and child report of effortful control collectively explained 26% of variance in color-word *WMIC* performance ($R^2 = .26$, $F(2, 37) = 6.44$, $p < .01$; see Table 24). However, neither child report of effortful control nor EVT performance emerged as independently significant contributors suggesting that collinearity (co-dependence of the independent variables) was present in the model. Examining the relation between the two sources evidenced that EVT performance and child report of effortful control were positively correlated ($r(38) = .51$, $p < .01$), such that EVT scores increased as self-reported effortful control increased. In short, although the two sources explained a significant amount of variance collectively, there was overlap in the explained variance such that neither source explained enough *unique* variance to be significant (see Figure 5).

For the fruit Stroop task, parent report of effortful control explained 14% of variance in *working memory* performance ($R^2 = .14$, $F(1, 37) = 6.23$, $p \leq .01$, $\beta = .38$, $t = 2.49$, $p \leq .01$; see Table 25). Here, increased parent report of effortful control positively impacted working memory performance, such that a

.38 unit increase in total items correct was seen with a one unit increase in reported effortful control scores. Parent report of effortful control also explained 20% of the variance in fruit Stroop *inhibitory control* performance (R^2 = .20, F(1, 37) = 9.13, p< .01, β = .45, t = 3.02, p < .01; see Table 26). Increased parent report of effortful control positively impacted inhibitory control performance, such that a .45 unit increase in total-completed interference scores (with higher scores indicative of less interference) was explained by a one unit increase in reported effortful control scores. Finally, parent report of effortful control explained 19% of variance in fruit Stroop *WMIC* performance (R^2 = .19, F(1, 37) = 8.49, p < .01, β = .43, t = 2.91, p < .01; see Table 27), where increased parent report of effortful control positively impacted inhibitory control performance such that a .43 unit increase in error-based interference scores (with higher scores indicative of less interference) was explained by a one unit increase in reported effortful control scores.

For the counting go/no-go task, hierarchical regression was used for determining the amount of variance explained in both working memory and WMIC performance, with the hypothesized sources of variability being entered in the first step and the additional sources of variability being entered in the second step to determine if they explained significantly more variance than the proposed model. Therefore, PPVT performance, left medial frontal and right lateral frontal baseline-to-task desynchronization (decreased power values associated with increased activation) were entered in Step 1, explaining 32% of the variance in *working memory* performance (R^2 = .32, F(3, 37) = 5.53, p < .01). In Step 1, PPVT performance emerged as the sole significant variable for explanation (β = -.31, t = -2.07, p ≤ .05). Bilateral parietal baseline-to-task alpha desynchronization (decreased power values associated with increased activation) was entered in Step 2, but did not result in a statistically significant increase in amount of explained variance (ΔR^2 = .05, F(2, 32) = 1.34, p = *ns*; see table 28). Therefore, only PPVT performance emerged from the proposed model as explaining a significant amount of unique variance in counting go/no-go working memory performance. Increased PPVT scores positively influenced counting go/no-go working memory performance, such that a .31 unit decrease in counting go/no-go omission errors was explained by a one unit increase in PPVT scores.

Hierarchical regression was also utilized to explain variance in counting go/no-go *WMIC* performance. PPVT performance and left medial frontal alpha desynchronization (decreased power values associated with increased activation) were entered in Step 1 to explain 30% of variance (R^2 = .30, F(2, 37) = 7.63, p < .01). Both factors emerged as significant ((β = .30, t = 2.06, p < .05; β = .37, t = 2.54, $p \leq$ .01, respectively). Bilateral parietal baseline-to-task alpha desynchronization (decreased power values associated with increased activation) was entered in Step 2, but did not result in a significant increase in explained variance (ΔR^2 = .04, F(2, 33) =1.01, p = *ns;* see Table 29). Both PPVT performance and left medial frontal desynchronization (decreased power values) emerged as sources explaining unique variance in counting go/no-go WMIC performance. Specifically, increased PPVT scores and increased left medial frontal activation (decreased power values) positively influenced WMIC performance. A .30 unit increase in total items correct was explained by a one unit increase in PPVT performance. Additionally, a .37 unit increase in total items correct was explained by a one unit increase in left medial frontal desynchronization. None of the proposed sources of variability were associated with counting go/no-go *inhibitory control* performance.

For the WCST task, none of the proposed sources of variability were associated with independent (WM, IC) or combined (WMIC) task performance. However, left frontal pole baseline-to-task alpha *synchronization* (increased power values) explained 19% of variance in WCST *working memory* performance (R^2 = .19, F(1, 37) = 8.64, p < .01, β = -.44, t = -2.94, p < .01; see Table 30). In this instance, increased alpha synchronization (increased power values denoted by negative difference scores) positively influenced WCST working memory performance, such that a .44 unit increase in conceptual level responses was explained by a one unit increase in left frontal pole alpha synchronization. Left frontal pole synchronization (increased power values) also explained 16% of variance in WCST *WMIC* performance (R^2 = .16, F(1, 37) = 6.58, $p \leq$ .01, β = -.39, t = -2.56, $p \leq$ .01; see Table 31). Here, increased alpha synchronization (increased power values denoted by negative difference scores) positively influenced WCST WMIC performance, such that a .39 unit increase in total items correct was explained by a one unit increase in left frontal pole alpha synchronization. None of the aforementioned sources of variability were associated with WCST *inhibitory control* performance.

Discussion

The Interactive Framework in Late Childhood

The first goal of the current study was to examine the interactive framework in late childhood. Because this framework has not previously been examined in late childhood, four tasks believed to require the integration of working memory and inhibitory control in the specified age range were chosen as WMIC measures. While the four tasks (the color-word Stroop, the fruit Stroop, the counting go/no-go and the WCST) were chosen based on their integrative nature, they were anticipated to vary in the weight of the individual (WM, IC) components' contribution to the overall WMIC measures. Indeed, regression analyses supported the hypothesis that the tasks differed in which component contributed most heavily to WMIC performance. As expected, the inhibitory control measures were more important to WMIC performance on the Stroop tasks relative to working memory, whereas working memory was more important in explaining WMIC performance on the WCST relative to inhibitory control. Additionally, the counting go-no-go task (which was hypothesized to be high on both working memory and inhibitory control) revealed the two components to be approximately equal in weight.

Based on the evidence that the four tasks differed in whether they were high or low on the independent (WM, IC) components, the finding that the tasks were not correlated with one another was not entirely unexpected. Despite the fact that the tasks were not related to one another, the relation between working memory and inhibitory control within each task would support the usefulness of the task as an interactive WMIC measure for late childhood. Indeed, all four tasks showed significant correlation between their respective working memory and inhibitory control measures. Finally, not only were the independent measures (WM, IC) correlated with one another for each task, but they were also correlated with the overall WMIC measures for each task. This finding, while seemingly apparent, needed to be evidenced because the WMIC measures were not mere additive calculations of the independent working memory and inhibitory control measures, but were separate measures hypothesized to incorporate both factors for success.

The fact that the four tasks individually showed interdependence of working memory and inhibitory control, despite the lack of relation across tasks, supported their usefulness as interactive measures and allowed for an in-depth examination of working memory and inhibitory control in the current late childhood sample. The overall findings concerning the interactive framework were consistent with the interactive theory of working memory and inhibitory control (Roberts & Pennington, 1990). Specifically, each task showed the relatedness of the independent components of working memory and inhibitory control as well the ability of the independent components to explain the overall WMIC measure for each task. Still, despite the fact that the four tasks were all interactive measures, they were not related to one another. Again, this is speculated to be due to the differing weights of the independent components of the tasks, and is consistent with past work suggesting both the unity and diversity of executive functions from late childhood to adulthood (Luna, et al., 2004; Miyake, et al., 2000).

Sources of Variability

The second main goal of the study was to identify sources of variability that contribute to WMIC performance in late childhood. Based on the aforementioned results supporting both the unity and diversity of executive functions, the analyses examining the sources of variability in each task looked at sources contributing to both the independent (WM, IC) and combined (WMIC) performance from each task in an attempt to determine whether different sources were related to the separate components within and across tasks. This was undertaken in an effort to explain the manner through which the sources of variability were related to WMIC performance. The unique sources of variability in the independent and combined components were determined through a series of correlations and regressions. The following section discusses the specific combinations of factors associated with successful performance both within and across the four tasks (see Table 32). Before examining the hypothesized sources of variability, it is important to note that age was eliminated as a possible source of variance because it was not significantly related to performance on any of the independent or combined components of the four tasks. This finding agrees with the majority of studies examining the late childhood range which have found comparable performance on these types of tasks (Gathercole, et al., 2004; Levin, et al., 1991; Welsh, et al., 1991).

Previous work has identified frontal lobe EEG activity, effortful control and surgency temperament factors, and language receptivity and expressivity as associated with WMIC performance in infancy, early childhood and middle childhood (e.g., Bell, Wolfe, & Adkins, in press; Wolfe & Bell, 2004). As there is a lack of work examining the interactive framework in late childhood, there has been no examination of the sources of variability in WMIC performance in this age range. Yet, there was ample reason to believe that the same sources of variability would emerge in the late childhood sample because only factors empirically or theoretically linked to both independent (WM, IC) components were included in the current examination (e.g., Barkley, 1997, Diamond, 2002, Luna, et al., 2004, Roberts & Pennington, 1990). Therefore, brain electrical activity, temperament, and language were examined in the current study. In the initial correlation analyses, all hypothesized sources (plus additional EEG sources) were examined to determine which factors were related to performance on the separate performance indices. Regression analyses were then performed using only significant factors from the correlation analyses in an attempt to understand which sources of variability could be used to explain performance on the given index.

Sources of Variability Within Tasks

In the following section, the sources of variability that were associated with performance on each task are noted. Additionally, the source(s) that emerged as significant for explaining unique variance in each performance index are discussed. The findings are initially discussed within each task.

Color-word Stroop. Total items correct, total-completed interference and error-based interference were the working memory, inhibitory control and WMIC measures, respectively, for the color-word Stroop. According to Roberts and Pennington (1996), correct responding in the incongruent color-word condition is reflective of working memory because it requires active maintenance and application of the rules to name the ink color and ignore the word. In the current study, this ability was associated with performance on the expressive language measure (EVT). EVT performance explained 21% of variance in total items correct on the color-word Stroop. The finding that expressive language performance was associated with working memory performance on this task is consistent with the role of the phonological loop component of Baddeley's working memory model which allows for verbal information to be manipulated and maintained.

A total-completed interference score was used as the measure of inhibitory control on the color-word Stroop (Adleman, et al., 2002; Archibald & Kerns, 1999). Based on work with children in the mid-to-late childhood range, scoring based on the total number of items completed, as opposed to correct, was used as it is thought to be a more sensitive and developmentally appropriate assessment when measuring inhibition in this age range (Archibald & Kerns, 1999). The interference score was calculated by subtracting the predicted score from the actual score (with more positive numbers reflecting less interference). Using this measure, total-completed interference was associated with child report of effortful control. Child report of effortful control explained 14% of variance in total-completed interference. Effortful control has been labeled as the self-regulatory temperament dimension (Wolfe & Bell, 2004). Barkley (1997b) has suggested that these regulatory abilities are critical for adaptive executive function skills, including inhibitory control. Therefore, the finding that less interference was in part contingent on greater effortful control is consistent with previous work.

The measure used to assess WMIC performance on the color-word Stroop was a modification of the total-completed interference score used to measure inhibitory control, basing the interference score on *total correct* (the working memory component) as opposed to *total completed*. This new score (error-based interference) was hypothesized to incorporate both working memory and inhibitory control as it incorporated the Roberts and Pennington (1996) definition of working memory while maintaining the basic interference formula (Adleman, et al., 2002). Not surprisingly then, WMIC performance (error-based interference) on the color-word Stroop was associated with expressive language (EVT) and child report of effortful control. Taken together, child report of effortful control and EVT performance explained 26% of variance in error-based interference. Separately, higher expressive language scores and higher self-report of effortful control were associated with higher WMIC scores. However, neither emerged as significant in a regression analysis, although the overall analysis was significant, meaning that there was too much overlapping variance shared by the pair. This finding complements work which suggests that language is an important self-regulatory trait that may serve as a link between effortful control and cognitive abilities, specifically attentional focusing and inhibition (Berk, 1992; Bronson, 2000; Kopp, 1989; Landry, et al., 2002).

Fruit Stroop Task. The fruit Stroop task was developed by Archibald and Kerns (1999) to serve as a non-reading measure of inhibition. However, it was discovered that the task was as highly correlated with working memory measures as inhibition measures. It was suggested that the necessity to recall the appropriate fruit colors activated working memory aspects. Because the fruit Stroop was modeled after the color-word Stroop and the formula for calculating the interference score was based on the same logic, the same measures of the independent (WM, IC) and combined (WMIC) components were retained for this task. Therefore, total items correct, total-completed interference and error-based interference were the working memory, inhibitory control and WMIC measures, respectively, for the fruit Stroop.

The working memory measure, total items correct, was associated with parent report of effortful control. Parent report of effortful control explained 14% of variance in total items correct on the fruit Stroop. Barkley (1997b) suggests that regulatory skills subsumed by effortful control are critical to adaptive executive functioning skills, including working memory. As mentioned, effortful control is comprised of attention, inhibition and activation control factors. According to the Kane and Engle executive-attention based working memory model, attentional skills provide the ability to maintain focus on the rules (name the color the fruit should be; do not name the color is the fruit appears in) in the face of interference (either environmental or task). Maintaining attention then should allow for less interference and greater inhibition (not naming the color the fruit is pictured in). Additionally, greater activation control which is necessary for maintaining and manipulating information (the rules) in working memory was probably critical for selecting the appropriate response of recalling the color the fruit was originally presented in.

Parent report of effortful control was also associated with performance on the inhibitory control measure (total-completed interference), explaining 20% of variance in total-completed interference. Here, the same skills that emerged as important for working memory performance emerged as important for inhibitory control performance as well. As mentioned, effortful control is thought to be critical to inhibitory control performance because it allows for focusing attention on the task at hand in the face of interference, deselecting the inappropriate information (the color currently being presented), and actually inhibiting the dominant response (name the color currently presented). This line of thought is consistent with past research and theory (Bell, Wolfe, & Adkins, in press; Barkley, 1997; Roberts & Pennington, 1996; Wolfe & Bell, 2004); however this finding may have been anticipated in part because the total-completed interference score was associated with successful performance on other age-appropriate working memory tasks in past research (Archibald & Kerns, 1999). Therefore, this measure may actually include both working memory and inhibitory control requirements.

Finally, error-based interference, which served as the WMIC measure for the fruit Stroop, was associated with parent report of effortful control. Here, parent report of effortful control explained 19% of variance in error-based interference. As this measure incorporated both working memory and inhibitory control, it follows that the same measure that emerged as critical for explaining independent (WM, IC) performance emerged as critical for explaining combined (WMIC) performance. In short, it seems impossible to partition the working memory and inhibition components of this task.

Counting go/no-go. The counting go/no-go task was developed to require both working memory and inhibitory control processes equally (Mostofsky, et al., 2003). Omission errors, commission errors and total correct were used, respectively, as working memory, inhibitory control and WMIC measures on the counting go/no-go task.

Based on past work with children in the mid-to-late childhood range evidencing significant relation between omission errors and working memory task performance (Archibald & Kerns, 1999), omission errors were used as the working memory index for the counting go/no-go. Omission errors were associated with performance on the PPVT as well as with alpha desynchronization in left medial frontal, right lateral frontal and bilateral parietal areas. These associations are consistent with past work evidencing medial and lateral frontal areas as critical for working memory performance (Curtis & D'Esposito, 2004; Hong, et al., 2000; Petrides, 2000) and with the proposal that a fronto-parietal network underlies working memory (Curtis & D'Esposito, 2004; Klingberg, O'Sullivan, & Roland, 1997; LaBar, Gitelman, Parrish, & Mesulam, 1999). Additionally, poor language comprehension has been shown to distinguish between high and low performance on working memory tasks in this age range (Nation, et al., 1999). Using sequential regression to determine the relative importance of these factors for working memory performance evidenced that 32% of variance in omission errors was explained by the proposed model, with PPVT performance being the sole significant factor that emerged from the model. It follows that basic language skills and comprehension provide the ability to understand task instructions and are important for successful performance on the given task. Considering the specific working memory requirement on the counting go/no-go task, omission errors occurred when the participant did not respond when s/he was supposed to respond. This could have been because the participant did not fully grasp the rules, felt rushed because response time was limited (≤ 1600 ms), and/or was confused about whether s/he was performing correctly as feedback was not provided. It may have been difficult for the participant to maintain and manipulate the information (how many green ships s/he had seen, whether it was an odd/even number, whether s/he was supposed to respond to red ships that followed odd/even green ships) if s/he did not fully comprehend the basic requirements of the task.

Commission errors were used as the inhibitory control index for the counting go/no-go task based on research with children in the specified age range evidencing that commission errors were significantly correlated with age-appropriate inhibition tasks (Archibald & Kerns, 1999). Commission errors were committed when the participant responded when s/he was not supposed to (i.e., rescued a red ship following an odd number of green ships). None of the hypothesized sources of variability were associated with or explained performance on the inhibitory control counting go/no-go measure. This finding was unexpected because the counting go/no-go was hypothesized, and appears to have been, equal (high) in working memory and inhibitory control demand, intuitively suggesting that sources similar to those that were associated with the Stroop task inhibitory control measures (effortful control) would have been associated with the counting go/no-go inhibitory control measure. The lack of findings here may have stemmed simply from the low amount of commission errors possible to make in this task (7 of 62). An abbreviated version of this task was employed specifically for this study to shorten administration time. Perhaps, employing the full length task in future studies, which would increase the number of possible commission errors, would evidence relation between the inhibitory control component and the proposed sources of variability.

Total correct was used as the WMIC performance index for the counting go/no-go task as it incorporated both working memory (omission errors) and inhibitory control (commission errors). Left medial frontal and bilateral parietal desynchronization and PPVT performance were associated with counting go/no-go WMIC performance. As mentioned previously, the fronto-parietal network has been associated with successful working memory performance (Curtis & D'Esposito, 2004; Klingberg, et al., 1997; LaBar, et al., 1999) and may have been associated with WMIC performance here as supporting the working memory requirements associated with task performance. Medial frontal activation (decreased power values), on the other hand, has been associated with successful performance on both working memory (Banich, et al., 2000) and inhibitory control (Bogorodzki, et al., 2005) tasks. In addition, both theory and empirical work support the role of the medial frontal region in interactive tasks (Diamond, 2002; Kane & Engle, 2002; Mostofsky, et al., 2003; Roberts & Pennington, 1996; Wolfe & Bell, 2004).

PPVT performance has also been associated with WMIC performance in past research, emerging as the most important factor in explaining variance in WMIC performance in preschoolers (Wolfe & Bell, 2004). From the aforementioned factors, only PPVT performance and left medial frontal alpha desynchronization emerged from the sequential regression analysis as explaining unique variance in WMIC performance. Together, PPVT performance and left medial frontal activation (decreased power values) explained 30% of variance in total correct on the counting go/no-go. These factors represent two of the three sources of variability hypothesized to explain variance in WMIC performance, brain electrical activity and language. Indeed, it was specifically hypothesized that activation (decreased power values) in the medial frontal region alone would explain variance in WMIC performance in the current sample as this region alone has emerged as predictive of WMIC performance by age 4.5 (Wolfe & Bell, 2004). This hypothesis was supported and even extended in that it was specifically the *left* medial frontal region which emerged as explanatory. The left medial frontal region is thought to be important for verbal-based information (Reuter-Lorenz, Jonides, & Smith, 2000). While this task did not require reading or naming colors, many of the children appeared to depend on verbal abilities to perform successfully as they counted the spaceships aloud or under their breath. This seemingly verbal-based maintenance and manipulation of information (working memory) may have helped the children to stay focused and block interference from the environment and past trials (inhibitory control). The finding that PPVT performance also emerged as a significant factor for understanding variance in counting go/no-go WMIC performance again suggests that basic comprehension and understanding of task instructions is important for task success. These abilities seem to have been a particularly important factor for success on the counting go/no-go task as it was high in both working memory and inhibitory control. It is suggested that the speed of the task paired with the lack of feedback did not allow for the participants to delay response, determine if they were responding correctly, or change tactics, which made understanding and maintaining the task instructions critical to successful performance.

Similar sources of variance were associated with performance on the working memory and WMIC measures of the counting go/no-go. This was not the case with the inhibitory control and WMIC measures as none of the proposed sources of variability were associated with performance on the counting go/no-go inhibitory control measure despite its prominent qualities resembling the well-established inhibition go/no-go tasks. Again, this finding may have been due to fewer possible commission errors (7 of 62) as opposed to omission errors (55 of 62). Increasing the number of possible errors may allow for determining sources of variability associated with this component in future research.

WCST. The Wisconsin Card Sorting Test was chosen as a WMIC measure high in working memory and low in inhibitory control (Roberts & Pennington, 1996). Conceptual level responses, perservative errors, and total correct were used, respectively, as the working memory, inhibitory control and WMIC measures.

Conceptual level responses denote series of three or more consecutive correct sorts thought to reflect insight into the sorting strategy (Heaton & PAR staff, 2003). It is implied that active maintenance of the sorting strategy is required for success. None of the proposed sources of variability were associated with performance on this measure. As previously noted, medial and lateral frontal alpha desynchronization has been associated with working memory performance (Curtis & D'Esposito, 2004; Hong, Lee, Kim, Kim, & Nam, 2000; Petrides, 2000).

However, this was not observed in the current sample. The observed alpha synchronization was evidenced in the orbitofrontal area. Past work has associated neural activity in this area with the reception of positive and negative feedback and with the act of mentally shifting set (Monchi, Petrides, Petre, Worsley, & Dagher, 2001). Although the WCST provides feedback ("right" or "wrong" visually displayed on the computer screen after a response) and is well-known for its set-shifting requirements (Heaton & PAR staff, 2003), working memory performance on the WCST was measured by conceptual level responses, which required maintaining the current set as opposed to shifting set. Therefore, the observed synchronization in the left frontal pole is suspected to be due to the emotional salience of the feedback. Another issue is that the pattern of activity observed was opposite of what was anticipated. Typically, alpha desynchronization (decreased power values) is associated with enhanced performance on cognitive tasks (Bell, 1998). Recent work, however, suggests that sustained positive emotion during a challenging cognitive task is associated with alpha synchronization and thus with improvements in cognitive performance (McCraty, 2001).

Finally, the observed synchronization (increased power values) pattern was left-localized which may have been due to the sustained *positive* emotion. It follows that participants showing greater left orbitofrontal (F1) alpha synchronization were those who were exhibiting greater conceptual level responses and thusly receiving more positive feedback (more visual displays of "right"). In past studies, more positive emotion has been associated with left frontal activation (decreased power values) and more negative emotion has been associated with right frontal activation (decreased power values) (e.g., Schmidt & Trainor, 2001). However, recent work by Panksepp and Bernatzky (2002) found that more positive emotion produced event-related synchronization, while more negative emotion produced event-related desynchronization. Taken together, these findings support the role of the left orbitofrontal region (F1) in explaining 19% of variance in conceptual level responses (working memory performance).

Perservative errors, continuing to respond based on a sorting principle that is incorrect, were used as the measure of inhibitory control performance on the WCST. Perservative errors are thought to be reflective of the inability to inhibit a learned strategy (Bull & Screif, 2001). Interestingly, none of the proposed sources of variability were related to inhibitory control performance on the WCST.

Total correct was used as the WMIC measure for the WCST task as it accounts for both conceptual level responses and perservative errors. Again, none of the proposed sources of variability were associated with performance on this measure. However, left orbitofrontal alpha synchronization was associated with WMIC performance on the WCST. Left frontal alpha synchronization which is thought to be associated with sustained positive feedback (McCraty, 2001; Panksepp and Bernatzky, 2002) explained 16% of variance in total items correct.

In sum, the same source (left orbitofrontal alpha synchronization) explained a significant amount of variance in both the working memory and WMIC performance measures on the WCST. An interesting aside regarding this task is that alpha synchronization was not associated with inhibitory control performance. This can easily be explained in that the inhibitory control measure was error-based, meaning that only negative feedback was associated with it and the orbitofrontal synchronization appears logically to be associated with positive feedback.

Sources of Variability Across Tasks

There was a great deal of variability across tasks in which sources contributed to independent and combined working memory and inhibitory control performance (see Table 32). In attempting to discern the variation observed in sources of variability across tasks, it is first necessary to compare and contrast the tasks. As stated previously, each task differed in the weight of the independent components of working memory and inhibitory control. The Stroop tasks were high in inhibitory control. The counting go/no-go was high (equal) in both working memory and inhibitory control and the WCST was high in working memory. All of the tasks were similar in that the WMIC measure was comprised of some variation of total items correct.

Brain Electrical Activity. Only the counting go/no-go task showed the hypothesized patterns of EEG activation, with medial frontal desynchronization (decreased power values associated with increased activation) emerging as the sole region associated with WMIC performance. The primary difference in the counting go/no-go and the other tasks is its more equal weighting of working memory and inhibitory control.

The only other task that showed any pattern associated with brain electrical activity was the WCST. Although, neither the brain region nor the pattern of activity was hypothesized, the findings are conceptually sound as left orbitofrontal alpha synchronization has been related to positive emotion associated with feedback (McCraty, 2001; Panksepp and Bernatzky, 2002). Indeed, this pattern was specific to the WCST as it was the only task that provided the participants with direct feedback on their performance. It should be noted here that the WCST and counting go/no-go required 64 and 62 responses, respectively. The WCST differed from the counting go/no-go, however, in that there was no set time limit for responses. As a matter of fact, the participants were blocked from responding for one second on the WCST while the card moved to the specified position, whereas the participant had a maximum of 1600 ms to make a response on the counting go/no-go task. The WCST took approximately one minute longer to complete on average than the counting go/no-go task despite the negligible difference in the number of required responses.

The finding that performance on the Stroop tasks was not associated with the hypothesized EEG pattern may have been because each condition of the Stroop lasted a mere 45 seconds during which time the participants noted their responses aloud. Speaking aloud may have interfered with the EEG recording. Additionally, the raw EEG for the Stroop tasks tended to have more artifact as the participants were more physically active (despite being reminded to sit still) during these tasks. The increased activity may have been due to anxiety in having the experimenter in the room recording responses during the tasks. Indeed, both the counting go/no-go and the WCST which evidenced significant brain electrical activity correlates were computer-administered and significantly longer in duration (approximately 4 and 5 minutes, respectively). In future research, it may be beneficial to employ a computerized version of the Stroop, which can be utilized to reduce the participant-experimenter interaction and to increase the amount of time for each condition.

Temperament. All of the tasks were similar in that no matter what the weights and requirements of the task were, child and parent report of surgency was not related to performance. Although parent report of surgency was associated with WMIC performance at 4.5 years (Wolfe & Bell, 2004) and child report of surgency was related to WMIC performance at 8 years (Bell, Wolfe, & Adkins, in press), surgency was not related to the independent or combined measures of working memory and inhibitory control in the current sample, suggesting that it may no longer be appropriate in normative samples in this developmental period. Perhaps surgency would be associated with task performance in non-normative samples, such as ADHD (Barkley, 1997; Rothbart & Jones, 1999).

Interestingly, only performance on the Stroop tasks was related to effortful control. Even more intriguing is that despite being positively correlated with one another, parent and child report of effortful control differed on the performance indices with which they were associated. Child report of effortful control was related to performance on the inhibitory control and WMIC indices of the color-word Stroop, whereas parent report of effortful control was related to all three measures on the fruit Stroop. The common factor between the Stroop tasks is the weighting of the independent components of working memory (low) and inhibitory control (high). The primary difference between the tasks is that the color-word Stroop is a reading-based task, whereas the fruit Stroop task was developed specifically to be a non-reading task. As the child ages, the world around him/her becomes increasingly more verbal and the abilities to read, communicate, and self-regulate become increasingly more important (Bronson, 2000). Indeed, child report of effortful control was positively correlated with expressive language and is thought to be related to WMIC performance on the color-word Stroop through its self-regulatory capacity.

Perhaps this distinction explains why child report of effortful control is related to color-word Stroop performance while parent report of effortful control is related to fruit Stroop performance. On the other hand, child report of effortful control appears to be related to the color-word Stroop through inhibitory control performance, whereas parent report of effortful control is probably related to the fruit Stroop through working memory performance as performance on all performance indices of the fruit Stroop have been associated with successful working memory performance in this age range (Archibald & Kerns, 1999). Additionally, the working memory indices of the Stroop tasks are correlated, but the inhibitory control and WMIC indices are not. This may be because the fruit Stroop, while weighted more highly on inhibitory control, has a greater emphasis on working memory than the color-word Stroop. This assertion seems reasonable as working memory performance on the fruit Stroop was not correlated with working memory performance on either of the tasks weighted high in working memory.

Neither child nor parent report of effortful control was related to performance on the counting go/no-go task and the WCST. The primary distinction between these tasks and the Stroop tasks, other than being computerized, is that both the counting go/no-go and WCST were high on working memory requirements. Additionally, inhibitory control performance on the computerized tasks was not associated with any of the proposed sources of variability. Therefore, effortful control may be vital for performance in instances where inhibitory control demand is high. Increasing the inhibitory control demand of the counting go/no-go tasks in future studies may help resolve this issue.

Language. Expressive language performance was related to working memory and WMIC performance on the color-word Stroop, while receptive language was related to working memory and WMIC performance on the counting go/no-go. The relation between working memory and language is well-established in the literature (e.g., Baddeley, 1996, 2003; Gathercole & Baddeley, 1993; Gathercole & Hitch, 1993; Gathercole, et al., 2004). Interestingly, the same language measures that are related to working memory in a task were related to WMIC performance in the same task, suggesting that language may contribute to WMIC performance specifically through its relation with working memory.

Past work has evidenced PPVT performance (receptive language) as associated with and emerging as the strongest predictor of WMIC performance in early childhood when examining the same overall model (Wolfe & Bell, 2004). More recent work has shown expressive language to be associated with WMIC performance in middle childhood (Bell, Wolfe, & Adkins, in press). To understand how both language receptivity and expressivity were related to WMIC performance, yet in separate tasks, we must examine the differences in these tasks. The main differences between the two tasks are the weighting of the independent components, the administration, and the base. The color-word Stroop task was high in inhibitory control, was administered by the researcher, and was verbal-based. The counting go/no-go task was high in both working memory and inhibitory control demands, was computer-administered, and was visuo-spatially-based. It is possible that expressive language may have been related to color-word Stroop WMIC performance in part through its relation to effortful control as neither emerged as significant in the overall regression due to shared variance. This hypothesis can be supported by current work suggesting that language is an important self-regulatory ability because of its link to effortful control (Kopp, 1989) and may enhance cognitive performance through its self-regulatory capacity (Berk, 1992; Bronson, 2000, Winsler, et al., 2000). Additionally, the unique variance contributed by expressive language may be through its relation to working memory where subvocal rehearsal is used to maintain the rules and manipulate information (Baddeley, 2000).

Receptive language, on the other hand, explained a significant amount of variance in counting go/no-go WMIC performance. Intuitively, understanding any task is critical for successful performance and this task, in particular, was probably the most difficult task as it was weighted high in both working memory and inhibitory control demand. Moreover, it appears that receptive language relates to WMIC performance through working memory. It has been suggested that participants without language impairment use a verbal code for processing information even in visuo-spatial tasks where the information has to be recoded first (Baldo, Dronkers, Wilkins, Ludy, Raskin, & Kim, 2004). If this is the case, the relation of PPVT performance (receptive language) to WMIC performance on the counting go/no-go may be through the requisite recoding of the information.

Conclusion

In conclusion, both unity and diversity of the executive functions working memory and inhibitory control were supported by the results of the current study. The findings that the independent (WM, IC) components of the tasks were not correlated across tasks and that different sources of variability are associated with successful performance on those components supports the diversity of working memory and inhibitory control. The findings that the independent components of working memory and inhibitory control were correlated within each task and that the sources of variability in those functions were similar to those reported in other studies of WMIC functioning suggests the unity or interactive nature of working memory and inhibitory control (e.g., Barkley, 1997; Brocki & Bohlin, 2004; Diamond, 2002; Duncan, et al., 1997; Kane & Engle, 2002; Luna, et al., 2004; Roberts & Pennington).

Based on the findings of the current study, it appears that all four tasks can be used to examine the *interactive* (WMIC) framework in late childhood. However, if the independent components are to be examined for their possible contribution to the interactive nature of the task, it is suggested that the fruit Stroop should be removed from consideration as it appears all three components have some degree of working memory demand. There may also be reason to consider removing the WCST from the current design in future work. The WCST is known to necessitate the use of several executive functions above and beyond working memory and inhibitory control, which makes partitioning the variance associated with specific components difficult due to task impurity (Burgess, 1997; Phillips, 1997).

Although two of the tasks (fruit Stroop and WCST) should be considered for removal in future designs examining working memory and inhibitory control, the other two tasks (counting go/no-go and color-word Stroop) that were utilized in the current study, appear to be fully appropriate for use with the current and future late childhood samples. Interestingly, the two tasks combined were related to all three proposed sources of variability, only in different manners. This finding may be in part due to the differing nature and demands of the tasks. The color-word Stroop was a more verbal-based task, whereas the counting go/no-go was visuo-spatial in nature. The color-word Stroop was high in inhibitory control, whereas the counting go/no-go appeared to be high in both working memory and inhibitory control. These differences may offer some insight into why task success was differentially associated with the proposed sources of variability.

The counting go/no-go task was the only task to emerge as related to the proposed electrophysiological correlates. Additionally, counting go/no-go task performance was also linked to receptive language. This task most closely matched the model previously found by Wolfe & Bell (2004) to be predictive of WMIC functioning in early childhood. Interestingly, with this late childhood sample, it was left medial frontal activation that emerged as the strongest source of unique variance in WMIC performance, whereas receptive language emerged as the strongest predictor of WMIC functioning in early childhood (Wolfe & Bell, 2004). As noted previously, activation of the medial frontal region is proposed to be associated with the interactive nature of working memory and inhibitory control (WMIC; Diamond, 2002; Kane & Engle, 2002).

The color-word Stroop also appears appropriate for continued examination of the independent and combined components of working memory and inhibitory control with late childhood samples. Successful task performance on the color-word Stroop was explained collectively by expressive language and child report of effortful control. This finding is perhaps the most intriguing of the study because it suggests that the two sources may combine in a self-regulatory capacity to enhance WMIC performance. Although this was only found to be the case for the color-word Stroop, it may be linked to the stringent verbal base of the task. If this is indeed the case, then there are implications for teaching children to use their language to regulate their thoughts and emotions which may have the additional bonus of enhancing cognitive performance. While this may seem quite the leap for findings from one study, there is support for the self-regulatory nature of language through its relation to effortful control (Kopp, 1989; Landry, et al., 2002).

It is noteworthy that successful performance on both the color-word Stroop and counting go/no-go was explained in part by language abilities. There is some evidence to suggest that participants without language disorders may use language as the predominant code in both verbal and visuo-spatial tasks by recoding visuo-spatial information from tasks into verbal information for processing (Baldo, et al., 2004;

Baddeley, 2000; Kwon, et al., 2002). If this is the case, then we may expect both receptive and expressive language to emerge as critical sources of variability in working memory and inhibitory control functioning in the future. Receptive language may be critical for coding the material in a manner in which it can be understood and expressive language may be important for both rehearsal and self-regulation.

Finally, when examining the interactive (WMIC) framework in the current late childhood sample, some advancement was made in explaining sources of variance. However, only 30% of variance in WMIC performance *at most* could be identified using the chosen WMIC measures. While this is informative, it does not allow for an adequate prediction model of cognitive functioning in this age range. Indeed, the findings suggest that our time may be better spent examining the independent components of working memory and inhibitory control to ascertain their contribution to WMIC performance. Following this line of research, using well-chosen tasks, may offer a wealth of insight into individual variability in executive functioning (WMIC) which is suggested to underlie adaptive daily functioning (Roberts & Pennington, 1996) and differentiate between normative and non-normative development (Barkley, 1997).

Limitations

The ability to generalize the findings of the current study is limited by two main factors. First, the sample was rather homogeneous. The majority of participants were Caucasian. Additionally, the majority of parents whose children participated in the study were well-educated (81% holding a college degree). Based on these limitations, extending the findings outside similar populations should be undertaken with caution.

Second, one of the tasks employed in the study, the color-word Stroop, can only be used in literate populations or the findings are invalid. Fortunately, the criteria for the task are not terribly stringent as it only requires the identification of four color words.

Because this study was the first of its kind to be executed with a late childhood sample, caution must be taken in generalizing the results. Indeed, replication and extension of the findings in the current study are needed for reliability and to make more extensive assertions.

Future Directions

To fully understand the unity and diversity of the executive function skills, working memory and inhibitory control, studies need to continue to include interactive tasks that allow for examination of the independent and combined components of working memory and inhibitory control. The counting go/no-go and color-word Stroop seem to be reasonable tasks for examining this design in late childhood and should extend well into middle childhood and adulthood. Adding a task that is high in working memory demand and meets the criteria of having both independent and combined components (without excessive task impurity) to replace the WCST is recommended. Also, based on the finding that the interactive tasks in the current study were not correlated with one another, adding other interactive (WMIC) tasks (see Diamond, 2002; Roberts & Pennington, 1996 for possibilities) to see which, if any, are correlated will allow us to examine the specific similarities that seem to underlie task relatedness. Examining the relation of working memory only and inhibitory control only tasks to more interactive tasks may also be beneficial for understanding the intricacies of the interactive (WMIC) tasks.

Longitudinal designs are also needed to understand the development of these components and to address change in unity and diversity as well as sources of variability across the lifespan. Although some work has been done in this area (e.g., Diamond, 2002; Wolfe & Bell, 2004), much more is needed before we have a firm grasp on the development of these facets. It would also be beneficial to explore other sources of variability that may be associated with independent and combined task performance both in specific developmental periods and across the lifespan.

In summary, there is an expansive literature suggesting that working memory and inhibitory control are critical skills underlying executive functioning and adaptive daily functioning (Brocki & Bohlin, 2004; Roberts & Pennington, 1996). There is further work to suggest that these skills may differentiate between normative and non-normative development in childhood (Barkley, 1997). More in-depth examinations of the independent and combined components of working memory and inhibitory control will be useful for understanding cognitive development and perhaps may eventually allow for intervention techniques to increase functioning in non-normative populations.

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Table 1.

Working Memory, Inhibitory Control and WMIC Performance Indices by Task

	Color-word Stroop	**Fruit Stroop**	**Counting Go/no-go**	**WCST**
Working Memory	Total correct incongruent condition	Total correct incongruent condition	Omission errors	Conceptual level responses
Inhibitory control	Total complete interference score	Total complete interference score	Commission errors	Perservative errors
WMIC	Total correct interference score	Total correct interference score	Total correct	Total correct

Table 2.

Descriptive Statistics for WMIC Task Performance Indices and Sources of Variability

Performance Index	**N**	**Minimum**	**Maximum**	**Mean**	**SD**
color-word Stroop WM	38	18.00	66.00	32.50	9.22
color-word Stroop IC	38	-8.44	29.33	1.32	6.34
color-word Stroop WMIC	38	-11.11	30.43	-1.09	7.31
fruit Stroop WM	38	20.00	52.00	34.42	6.82
fruit Stroop IC	38	-2.71	13.76	7.32	4.29
fruit Stroop WMIC	38	-6.44	13.46	5.69	5.04
counting go/no-go WM	38	.00	9.00	1.79	1.88
counting go/no-go IC	38	49.00	61.00	57.84	2.85
counting go/no-go WMIC	38	11.00	51.00	38.24	9.57
WCST WM	38	3.00	27.00	10.00	4.64
WCST IC	38	20.00	55.00	44.08	6.70
WCST WMIC	38	49.00	61.00	57.84	2.85
language expressivity EVT	38	77.00	132.00	99.32	11.46
language receptivity PPVT	38	90.00	144.00	118.50	12.27
parent report effortful control	38	1.86	4.69	3.24	.66
parent report surgency	38	1.90	4.50	3.36	.62
self-report effortful control	38	2.47	4.63	3.55	.58
self-report surgency	38	1.75	4.33	3.16	.71

Table 3.

Correlations Among WMIC Scores for WMIC Tasks (n = 38)

	^{WMIC}CW Stroop$_a$	^{WMIC}Fruit Stroop$_b$	^{WMIC}CGNG$_c$	^{WMIC}WCST$_d$
^{WMIC}CW Stroop$_a$	-			
^{WMIC}Fruit Stroop$_b$	.06(.71)	-		
^{WMIC}CGNG$_c$	.01(.95)	.07(.65)	-	
^{WMIC}WCST$_d$	.28(.08)	.30(.06)	-.08(.61)	-
Age	-.17(.28)	.02(.89)	-.19(.24)	-.29(.07)

$_a$ total correct cw interference score
$_b$ total correct fruit interference score
$_c$ cgng total correct
$_d$ wcst total correct

Table 4.

Correlations Among Working Memory Scores for WMIC Tasks and Age (n = 38)

	^{WM}CW Stroop$_a$	^{WM} Fruit Stroop$_b$	^{WM}CGNG$_c$	^{WM}WCST$_d$
^{WM}CW Stroop$_a$	-			
^{WM} Fruit Stroop$_b$	**.51**(.00)**	-		
^{WM}CGNG$_c$	-.15(.36)	-.07(.64)	-	
^{WM}WCST$_d$	.04(.79)	-.01(.94)	.01(.93)	-
Age	.06(.71)	.22(.18)	.29(.07)	-.30(.06)

$_a$ total correct cw
$_b$ total correct if
$_c$ cgng omission errors
$_d$ wcst conceptual level responses

Table 5.

Correlations Among Inhibitory Control Scores for WMIC Tasks and Age (n = 38)

	^{IC}CW Stroop$_a$	^{IC}Fruit Stroop$_b$	^{IC}CGNG$_c$	^{IC}WCST$_d$
^{IC}CW Stroop$_a$	-			
^{IC}Fruit Stroop$_b$	.10(.54)	-		
^{IC}CGNG$_c$	.22(.18)	-.03(.84)	-	
^{IC}WCST$_d$	-.19(.23)	-.22(.18)	-.12(.45)	-
Age	-.18(.26)	-.01(.94)	-.01(.94)	.27(.09)

$_a$ ak cw interference score
$_b$ ak fruit interference score
$_c$ cgng commission errors
$_d$ wcst perservative errors

Table 6.

Correlations Among Working Memory and Inhibitory Control Scores for WMIC Tasks (n = 38)

	^{IC}CW Stroop$_a$	^{IC}Fruit Stroop$_b$	^{IC}CGNG$_c$	^{IC}WCST$_d$
^{WM}CW Stroop$_e$	**.73**(.00)**	-.05(.75)	-.03(.82)	-.07(.67)
^{WM} Fruit Stroop$_f$	.15(.34)	**.53**(.00)**	-.31(.06)	-.13(.43)
^{WM}CGNG$_g$	-.12(.44)	-.02(.88)	**.43**(.00)**	.10(.52)
^{WM}WCST$_h$	.29(.07)	.23(.15)	.29(.07)	**-.71**(.00)**

$_a$ ak cw interference score
$_b$ ak fruit interference score
$_c$ cgng commission errors
$_d$ wcst perservative errors
$_e$ total correct cw
$_f$ total correct if
$_g$ cgng omission errors
$_h$ wcst conceptual level responses

Table 7.

Correlations Among WM and WMIC Scores for WMIC Tasks (n = 38)

	^{WMIC}CW Stroop$_a$	^{WMIC}Fruit Stroop$_b$	^{WMIC}CGNG$_c$	^{WMIC}WCST$_d$
^{WM}CW Stroop$_e$	**.82**(.00)**	-.02(.89)	.11(.48)	.03(.82)
^{WM} Fruit Stroop$_f$	.20(.22)	**.63**(.00)**	.20(.21)	.03(.85)
^{WM}CGNG$_g$	-.15(.34)	-.04(.80)	**-.88**(.00)**	-.06(.69)
^{WM}WCST$_h$	.26(.10)	.22(.18)	-.16(.33)	**.96**(.00)**

$_a$ total correct cw interference score
$_b$ total correct fruit interference score
$_c$ cgng total correct
$_d$ wcst total correct

$_e$ total correct cw
$_f$ total correct if
$_g$ cgng omission errors
$_h$ wcst conceptual level responses

Table 8.

Correlations Among IC and WMIC Scores for WMIC Tasks (n = 38)

	^{WMIC}CW Stroop$_a$	^{WMIC}Fruit Stroop$_b$	^{WMIC}CGNG$_c$	^{WMIC}WCST$_d$
^{IC}CW Stroop$_e$	**.94**(.00)**	.07(.64)	-.03(.84)	.28(.08)
^{IC}Fruit Stroop$_f$	.07(.66)	**.92**(.00)**	.01(.90)	.30(.06)
^{IC}CGNG$_g$	.18(.27)	-.10(.52)	**-.79**(.00)**	.25(.12)
^{IC}WCST$_h$	-.19(.23)	-.25(.12)	-.01(.95)	**-.78**(.00)**

$_a$ total correct cw interference score
$_b$ total correct fruit interference score
$_c$ cgng total correct
$_d$ wcst total correct

$_e$ ak cw interference score
$_f$ ak fruit interference score
$_g$ cgng commission errors
$_h$ wcst perservative errors

Table 9.

Correlations Among Baseline-to-Task EEG Changes and Color-Word Scores (n = 38)

	^{WM}CW Stroop$_{a}$	^{IC}CW Stroop$_{b}$	^{WMIC}CW Stroop$_{c}$
F1	-.10(.54)	-.10(.53)	-.03(.82)
F2	-.24(.14)	-.15(.36)	-.10(.51)
F3	-.18(.25)	-.23(.16)	-.16(.32)
F4	-.25(.11)	-.32*(.04)	-.23(.16)
F7	-.18(.26)	-.29(.07)	-.19(.25)
F8	-.17(.30)	-.17(.30)	-.07(.64)
C3	-.10(.52)	-.17(.30)	-.11(.49)
C4	-.11(.47)	-.35*(.02)	-.28(.08)
T3	-.05(.75)	-.18(.27)	-.09(.58)
T4	-.26(.11)	-.25(.13)	-.20(.21)
T5	-.15(.38)	-.00(.99)	.01(.95)
T6	-.02(.89)	-.04(.81)	.01(.96)
P3	-.05(.74)	-.14(.40)	-.06(.69)
P4	-.02(.89)	-.26(.11)	-.15(.34)
O1	.02(.89)	.02(.90)	.08(.61)
O2	-.01(.92)	-.07(.64)	-.03(.84)

$_{a}$ total correct cw
$_{b}$ ak cw interference score
$_{c}$ cw interference score

Table 10.

Correlations Among Baseline-to-Task EEG Changes and Fruit-Stroop Scores (n = 38)

	^{WM}Fruit Stroop$_a$	^{IC}Fruit Stroop$_b$	^{WMIC}Fruit Stroop$_c$
F1	-.15(.34)	-.05(.74)	-.13(.41)
F2	-.24(.14)	-.14(.37)	-.17(.29)
F3	-.14(.38)	-.05(.75)	-.08(.62)
F4	-.17(.29)	-.04(.77)	-.08(.62)
F7	-.16(.31)	-.04(.80)	-.01(.92)
F8	-.09(.55)	-.18(.27)	-.09(.59)
C3	.11(.51)	.11(.49)	.04(.76)
C4	.08(.63)	.07(.64)	.04(.80)
T3	.02(.89)	.15(.35)	.14(.38)
T4	-.15(.35)	-.06(.71)	.00(.98)
T5	-.16(.34)	.00(.98)	-.05(.74)
T6	-.06(.71)	-.01(.95)	.00(.98)
P3	-.02(.87)	.01(.94)	-.09(.56)
P4	.08(.61)	.07(.63)	.04(.79)
O1	-.05(.73)	.08(.60)	.09(.56)
O2	.06(.70)	.03(.81)	.10(.55)

$_a$ total correct incongruent fruit
$_b$ ak fruit interference score
$_c$ fruit interference score

Table 11.

Correlations Among Baseline-to-Task EEG Changes and Counting Go/no-go Scores (n = 38)

	$^{WM}CGNG_a$	$^{IC}CGNG_b$	$^{WMIC}CGNG_c$
F1	-.26(.10)	-.22(.17)	.28(.08)
F2	-.30(.06)	-.10(.53)	.24(.13)
F3	**-.48**(.00)**	-.30(.06)	**.46**(.00)**
F4	-.36*(.02)	-.09(.58)	.27(.09)
F7	-.34*(.03)	-.28(.08)	.37*(.02)
F8	**-.39*(.01)**	-.19(.25)	.35*(.02)
C3	-.23(.15)	-.29(.07)	.30(.06)
C4	.01(.94)	-.19(.24)	.08(.60)
T3	-.20(.21)	-.05(.75)	.17(.30)
T4	-.39*(.02)	-.17(.31)	.36*(.02)
T5	-.29(.08)	.02(.88)	.19(.25)
T6	-.35*(.03)	-.25(.12)	.38*(.02)
P3	**-.49**(.00)**	-.28(.08)	**.46**(.00)**
P4	**-.47**(.00)**	-.28(.08)	**.45**(.00)**
O1	-.15(.36)	.07(.66)	.05(.73)
O2	-.13(.41)	.03(.85)	.06(.71)

$_a$ cgng omission errors
$_b$ cgng commission errors
$_c$ cgng total correct

Table 12.

Correlations Among Baseline-to-Task EEG Changes and WCST Scores (n = 38)

	$^{WM}WCST_{a}$	$^{IC}WCST_{b}$	$^{WMIC}WCST_{c}$
F1	**-.44**(.00)**	.37*(.02)	**-.39**(.01)**
F2	-.37*(.02)	.29(.07)	-.29(.07)
F3	-.16(.31)	.21(.18)	-.15(.34)
F4	-.11(.50)	.15(.35)	-.04(.77)
F7	-.27(.09)	.32*(.04)	-.24(.14)
F8	-.11(.49)	.29(.07)	-.05(.75)
C3	.09(.56)	.23(.16)	.04(.79)
C4	-.29(.07)	.20(.21)	-.30(.06)
T3	-.14(.38)	.25(.13)	-.20(.22)
T4	-.35*(.03)	.32*(.05)	-.25(.12)
T5	-.03(.85)	.07(.67)	.01(.94)
T6	-.35*(.03)	.30(.07)	-.27(.11)
P3	-.08(.61)	.18(.26)	-.05(.72)
P4	-.28(.08)	.26(.10)	-.23(.16)
O1	-.16(.33)	.02(.87)	-.037(.82)
O2	-.15(.34)	.11(.48)	-.08(.60)

$_{a}$ wcst conceptual level responses
$_{b}$ wcst perservative errors
$_{c}$ wcst total correct

Table 13.

Correlations Among WM Scores and Parent and Child Effortful Control Scores (n = 38)

	^{WM}CW Stroop$_{a}$	^{WM} Fruit Stroop$_{b}$	^{WM}CGNG$_{c}$	^{WM}WCST$_{d}$
PEATQ$_{EC}$	.15(.35)	**.38**(.01)**	.04(.80)	-.02(.89)
EATQ$_{EC}$	.24(.14)	.04(.79)	-.13(.41)	.30(.06)

$_{a}$ total correct cw
$_{b}$ total correct if
$_{c}$ cgng omission errors
$_{d}$ wcst conceptual level responses

$_{EC}$ effortful control

PEATQ parent report
EATQ child report

Table 14.

Correlations Among IC Scores for WMIC Tasks and Effortful Control Scores (n =38)

	^{IC}CW Stroop$_a$	^{IC}Fruit Stroop$_b$	^{IC}CGNG$_c$	^{IC}WCST$_d$
PEATQ$_{EC}$	.17(.29)	**.45**(.00)**	-.15(.36)	-.12(.46)
EATQ$_{EC}$	**.38**(.01)**	.25(.12)	-.01(.91)	-.29(.07)

$_a$ ak cw interference score
$_b$ ak fruit interference score
$_c$ cgng commission errors
$_d$ wcst perservative errors

$_{EC}$ effortful control

PEATQ parent report
EATQ child report

Table 15.

Correlations Among WMIC Scores for WMIC Tasks and Effortful Control Scores (n = 38)

	^{WMIC}CW Stroop$_a$	^{WMIC}Fruit Stroop$_b$	^{WMIC}CGNG$_c$	^{WMIC}WCST$_d$
PEATQ$_{EC}$	.18(.26)	**.43**(.00)**	.05(.74)	.07(.64)
EATQ$_{EC}$	**.44**(.00)**	.26(.10)	.11(.49)	.35*(.03)

$_a$ total correct cw interference score
$_b$ total correct fruit interference score
$_c$ cgng total correct
$_d$ wcst total correct

$_{EC}$ effortful control

PEATQ parent report
EATQ child report

Table 16.

Correlations Among WM Scores and Parent and Child Surgency Control Scores (n = 38)

	^{WM}CW Stroop$_a$	^{WM} Fruit Stroop$_b$	^{WM}CGNG$_c$	^{WM}WCST$_d$
PEATQ$_{SURG}$	.21(.20)	.21(.20)	-.02(.86)	.15(.34)
EATQ$_{SURG}$	.12(.45)	-.18(.27)	-.02(.88)	.24(.14)

$_a$ total correct cw
$_b$ total correct if
$_c$ cgng omission errors
$_d$ wcst conceptual level responses

$_{SURG}$ surgency

PEATQ parent report
EATQ child report

Table 17.

Correlations Among IC Scores for WMIC Tasks and Parent and Child Surgency Scores (n =38)

	^{IC}CW Stroop$_a$	^{IC}Fruit Stroop$_b$	^{IC}CGNG$_c$	^{IC}WCST$_d$
PEATQ$_{SURG}$	.14(.40)	.16(.32)	.06(.70)	-.22(.16)
EATQ$_{SURG}$	.21(.19)	.00(.97)	.22(.17)	-.28(.08)

$_a$ ak cw interference score
$_b$ ak fruit interference score
$_c$ cgng commission errors
$_d$ wcst perservative errors

$_{SURG}$ surgency

PEATQ parent report
EATQ child report

Table 18.

Correlations Among WMIC Scores for WMIC Tasks and Surgency Scores (n = 38)

	^{WMIC}CW Stroop$_a$	^{WMIC}Fruit Stroop$_b$	^{WMIC}CGNG$_c$	^{WMIC}WCST$_d$
PEATQ$_{SURG}$	.23(.15)	.21(.19)	-.01(.95)	.19(.24)
EATQ$_{SURG}$	.26(.11)	-.03(.85)	-.08(.60)	.25(.12)

$_a$ total correct cw interference score
$_b$ total correct fruit interference score
$_c$ cgng total correct
$_d$ wcst total correct

$_{SURG}$ surgency

PEATQ parent report
EATQ child report

Table 19.

Correlations Among WM Scores and Expressive and Receptive Language Scores (n = 38)

	^{WM}CW Stroop$_a$	^{WM} Fruit Stroop$_b$	^{WM}CGNG$_c$	^{WM}WCST$_d$
EVT$_{STD}$	**.46**(.00)**	.34*(.03)	-.33*(.03)	.18(.27)
PPVT$_{STD}$	.16(.33)	.01(.92)	**-.43**(.00)**	.06(.67)

$_a$ total correct cw
$_b$ total correct if
$_c$ cgng omission errors
$_d$ wcst conceptual level responses

$_{STD}$ standard language scores

EVT   Expressive Vocabulary Test
PPVT Peabody Picture Vocabulary Test

Table 20.

Correlations Among IC Scores and Expressive and Receptive Language Scores (n = 38)

	^{IC}CW Stroop$_a$	^{IC}Fruit Stroop$_b$	^{IC}CGNG$_c$	^{IC}WCST$_d$
EVT$_{STD}$	.35*(.02)	.24(.13)	-.06(.68)	-.35*(.02)
PPVT$_{STD}$	.06(.70)	-.04(.79)	-.25(.12)	-.17(.29)

$_a$ ak cw interference score
$_b$ ak fruit interference score
$_c$ cgng commission errors
$_d$ wcst perservative errors

$_{STD}$ standard language scores

EVT Expressive Vocabulary Test
PPVT Peabody Picture Vocabulary Test

Table 21.

Correlations Among WMIC Scores and Expressive and Receptive Language Scores (n =38)

	^{WMIC}CW Stroop$_a$	^{WMIC}Fruit Stroop$_b$	^{WMIC}CGNG$_c$	^{WMIC}WCST$_d$
EVT$_{STD}$	**.45**(.00)**	.26(.11)	.25(.11)	.26(.11)
PPVT$_{STD}$	.19(.24)	.00(.98)	**.41**(.00)**	.16(.32)

$_a$ total correct cw interference score
$_b$ total correct fruit interference score
$_c$ cgng total correct
$_d$ wcst total correct

$_{STD}$ standard language scores

EVT Expressive Vocabulary Test
PPVT Peabody Picture Vocabulary Test

Table 22.

Summary of Linear Regression Analysis for Variables Explaining WM Performance on the Color-Word Stroop Task (n = 38)

Variable	B	SE B	β	*t*	*p*
EVT_{STD}	.37	.11	.46	3.10	.004

Note. R^2 = .21 for the model. *p* = .004

Table 23.

Summary of Linear Regression Analysis for Variables Explaining IC Performance on the Color-Word Stroop Task (n = 38)

Variable	B	SE B	β	*t*	*p*
$EATQ_{EC}$	4.19	1.67	.38	2.49	.01

Note. R^2 = .14 for the model. $p = .01$

Table 24.

Summary of Linear Regression Analysis for Variables Explaining WMIC Performance on the Color-Word Stroop Task (n = 38)

Variable	B	SE B	β	*t*	*p*
$EATQ_{EC}$	3.68	2.12	.29	1.74	.09
EVT_{STD}	.19	.10	.30	1.79	.08

Note. R^2 = .26 for the model. p = .004

Table 25.

Summary of Linear Regression Analysis for Variables Explaining WM Performance on the Fruit Stroop Task (n = 38)

Variable	B	SE B	β	*t*	*p*
$PEATQ_{EC}$	3.98	1.59	.38	2.49	.01

Note. R^2 = .14 for the model. p = .01

Table 26.

Summary of Linear Regression Analysis for Variables Explaining IC Performance on the Fruit Stroop Task (n = 38)

Variable	B	SE B	β	*t*	*p*
$PEATQ_{EC}$	2.93	.97	.45	3.02	.005

Note. R^2 = .20 for the model. p = .005

Table 27.

Summary of Linear Regression Analysis for Variables Explaining WMIC Performance on the Fruit Stroop Task (n = 38)

Variable	B	SE B	β	*t*	*p*
$PEATQ_{EC}$	3.34	1.14	.43	2.91	.006

Note. R^2 = .19 for the model. *p* = .006

Table 28.

Summary of Hierarchical Regression Analysis for Variables Explaining WM Performance on the Counting Go/no-go Task (n = 38)

Variable	B	SE B	β	*t*	*p*
Step 1					
$PPVT_{STD}$	-.04	.02	-.31	-2.07	.04
$F3_{CGNGDIFF}$	-2.54	1.32	-.36	-1.92	.06
$F8_{CGNGDIFF}$	-.23	1.34	-.03	-.17	.86
Step 2					
$PPVT_{STD}$	-.04	.02	-.28	-1.83	.07
$F3_{CGNGDIFF}$	-.37	1.87	-.05	-.19	.84
$F8_{CGNGDIFF}$	-.14	1.46	-.02	-.09	.92
$P3_{CGNGDIFF}$	-.68	1.05	-.15	-.65	.51
$P4_{CGNGDIFF}$	-1.23	.83	-.29	-1.47	.15

Note. R^2 = .32 for Step 1, p = .003; ΔR^2 = .05 for Step 2, p = *ns*.

Table 29.

Summary of Hierarchical Regression Analysis for Variables Explaining WMIC Performance on the Counting Go/no-go Task (n = 38)

Variable	B	SE B	β	*t*	*p*
<u>Step 1</u>					
$PPVT_{STD}$	.07	.03	.30	2.06	.04
$F3_{CGNGDIFF}$	3.96	1.55	.37	2.54	.01
<u>Step 2</u>					
$PPVT_{STD}$	.06	.03	.28	1.81	.07
$F3_{CGNGDIFF}$	1.08	2.72	.10	.39	.69
$P3_{CGNGDIFF}$	.76	1.49	.11	.51	.61
$P4_{CNGDIFF}$	1.70	1.27	.26	1.33	.19

Note. R^2 = .30 for Step 1, p = .002; ΔR^2 = .04 for Step 2, p = *ns*.

Table 30.

Summary of Linear Regression Analysis for Variables Explaining WM Performance on the WCST Task (n = 38)

Variable	B	SE B	β	*t*	*p*
$F1_{WCSTDIFF}$	-13.60	4.62	-.44	-2.94	.006

Note. R^2 = .19 for the model. p = .006

Table 31.

Summary of Linear Regression Analysis for Variables Explaining WMIC Performance on the WCST Task (n = 38)

Variable	B	SE B	β	*t*	*p*
$F1_{WCSTDIFF}$	-8.51	3.31	-.39	-2.56	.01

Note. R^2 = .15 for the model. *p* = .01

Table 32.

Sources of Variability Associated with Successful Performance by Task and Component

$\mathbf{CW_{WM}}$	$\mathbf{Fruit_{WM}}$	$\mathbf{CGNG_{WM}}$	$\mathbf{WCST_{WM}}$
STDEVT	**PEATQEC**	**STDPPVT** F3 F8 P3 P4	**F1**
$\mathbf{CW_{IC}}$	$\mathbf{Fruit_{IC}}$	$\mathbf{CGNG_{IC}}$	$\mathbf{WCST_{IC}}$
EATQEC	**PEATQEC**		
$\mathbf{CW_{WMIC}}$	$\mathbf{Fruit_{WMIC}}$	$\mathbf{CGNG_{WMIC}}$	$\mathbf{WCST_{WMIC}}$
EATQEC STDEVT	**PEATQEC**	**STDPPVT** **F3** P3 P4	F1

Note: All sources listed were significantly correlated with performance on the specified index. Bolded sources contributed unique variance to the specific index.

Figure 1. Color Word Stroop Stimuli.

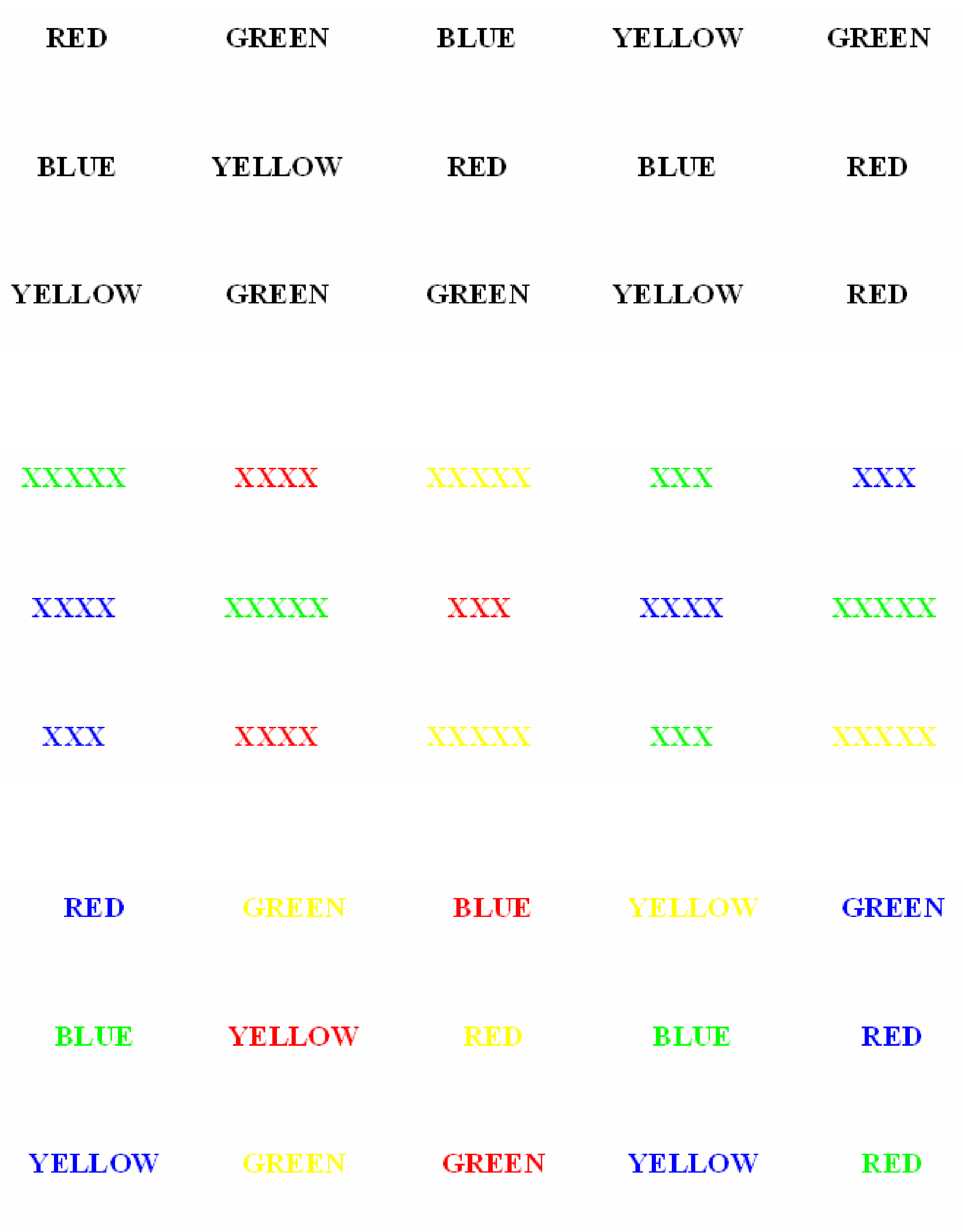


Figure 2. Fruit Stroop Stimuli.

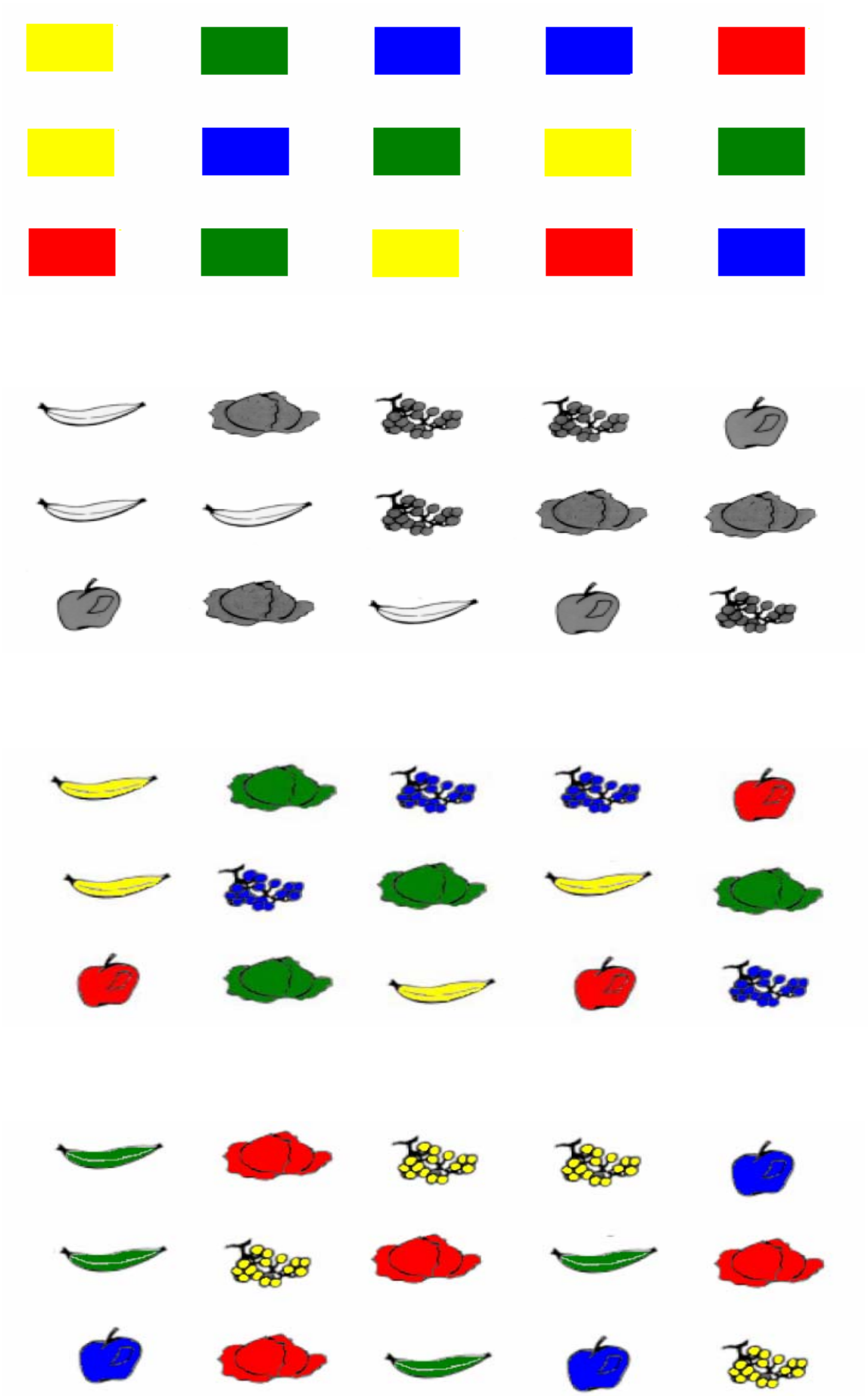


Figure 3. Counting Go/No-Go Task.

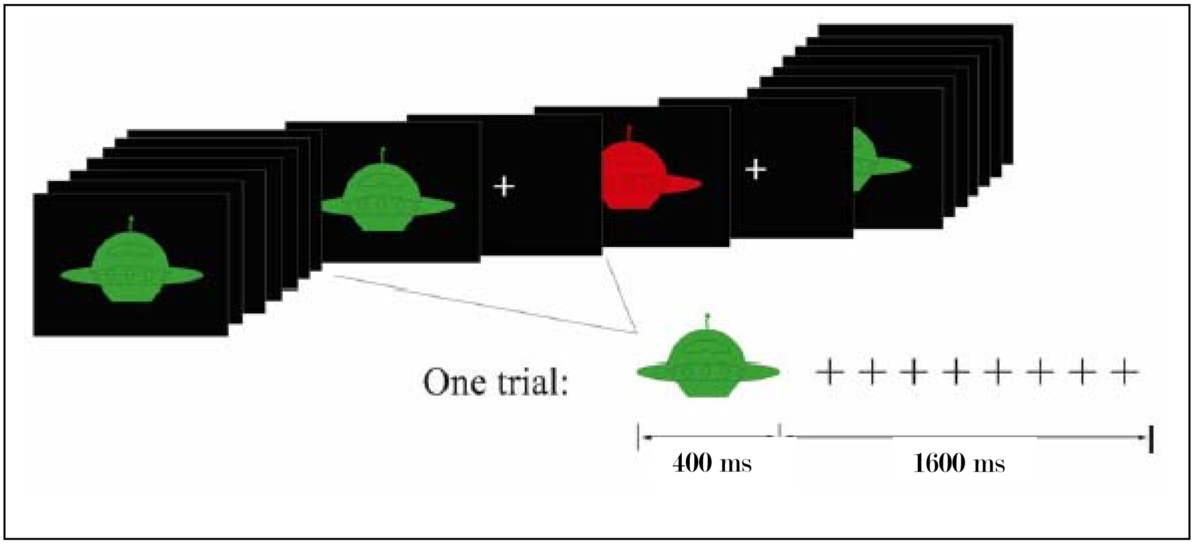


Figure 4. Computerized Wisconsin Card Sorting Test-64 (WCST-64:SP2).

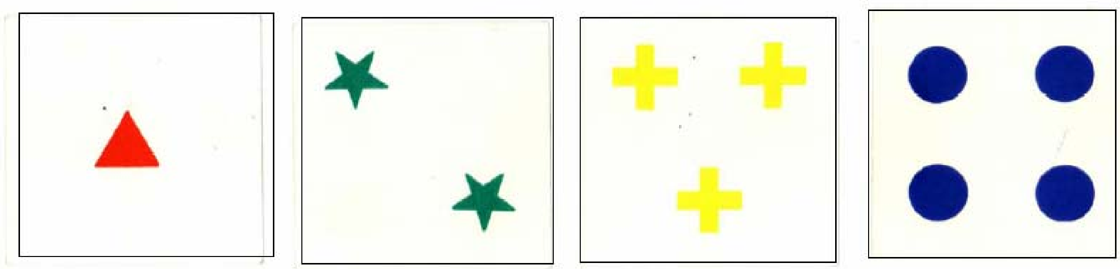
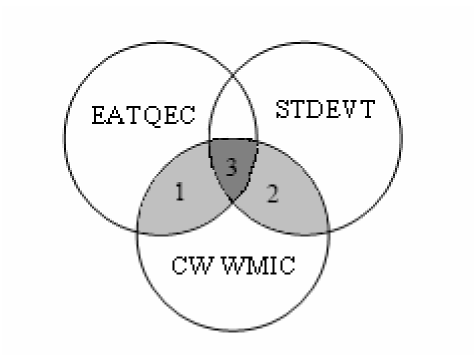


Figure 5. Venn Diagram illustrating the shared variance (covariance) among color-word Stroop WMIC performance, child report of effortful control, and EVT performance.



1 = (including area 3) variance shared by CW WMIC and EATQEC (r^2 = .19)
2 = (including area 3) variance shared by CW WMIC and EVT (r^2 = .20)
(1 + 2) - 3 = variance of CW WMIC accounted for by EATQEC and EVT (R^2 = .26)

Appendix A – Campus Recruitment Notice

Virginia Tech Home | VT News Home | About Virginia Tech News | Contact Us

Virginia Tech News

Enter search keywc Go

Blacksburg: Fair 72°F (22°C)

11:21 am, Friday Sep 9, 2005

News
- Top Stories
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Campus Notices

Administrative Calendar

Events Calendar

Awards
- Faculty Scholar of the Week
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Campus Notice

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Pre-teens sought for child development study

The Developmental Cognitive Neuroscience Lab in the Psychology Department at Virginia Tech is looking for children between the ages of 10-12.5 to participate in a study about brain development. The study takes about an hour and involves playing games on a laptop, participating in a short interview, playing a couple of word games and playing a couple of flash card games.

Children will receive a $10 gift card to Books-a-Million for their participation. Interested persons should contact Denise Adkins at dradkins@vt.edu, or call (540) 231-2320. Go here to learn more about the Developmental Cognitive Neuroscience Lab and the Child Development Project.

More Campus Notices

Appendix B – Recruitment Letter

Child Development Project

date

Dear Parents:

Here at Virginia Tech, we are studying the development of memory, language, brain activity, and behavior in late childhood and we would like to invite you and your child to participate in our latest research study. We got your name from our database of children and parents who have been contacted about possible research participation in our research studies or from a friend or parent that had a child participate and thinks you and your child might also enjoy the experience!

Participation in the study requires only one trip to the lab where parents and children will spend approximately 60 minutes with us playing computer games and word games. Children also get an opportunity to see what their brain waves look like on a computer monitor. **All children who come into the research lab for this study will receive a $10 gift card from Books-a-Million for their participation**. We will be recruiting 40 children between the ages of 10 and 12 for this study. A letter will be sent to parents upon completion of the study to report some of our initial research findings from this project.

Would you be interested in hearing more about this study? We will be calling you within the next few days to talk with you about our study. As always, 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. You can read about similar *Infant and Child Development Projects* and see photos of infants and children who have been involved with our studies.

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 e-mail at *dradkins@vt.edu*. Thank you and we look forward to talking with you!

Sincerely,

Denise R. Adkins, M.S.
Graduate Student in Psychology

Martha Ann Bell, Ph.D.
Associate Professor of Psychology

Appendix C - Parental Consent Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Parental Consent Form

Title of Project: "Cognitive Development in Middle Childhood"
Investigators: Martha Ann Bell, Ph.D., Denise R. Adkins

I. Purpose of this Research

You and your child have been invited to participate in a research project investigating the development of memory and language skills. Specifically, we are examining how brainwave and heart rate activity are associated with task performance. The information we gather in this research study will further our knowledge of how children develop important memory and language skills. A total of 40 children and parents will be participating in this study.

II. Procedures

This study involves one 60-minute visit to the Child Development Project Lab (Williams 348) at Virginia Tech. The visit will occur when your child is between 10-12 years of age. The entire session will be videotaped. This study involves 2 questionnaires (General Information Questionnaire and Temperament Questionnaire). We ask you to try to complete these forms at home prior to your child's visit to our research lab.

Upon arriving at the lab, we will show you all the lab equipment (including the EEG cap) that will be used during your child's visit to the lab. Then, you will be asked to sign an informed consent form identical to this one that details information about the questionnaires and your child's visit to the lab.

In general, a cap that helps us to collect brainwave activity will be placed on your child's head. This cap looks and fits like a swim cap. In order to collect brain-wave activity, gel will be applied to your child's hair through little holes in the cap. Heart rate patches will be placed on the child's back. These procedures are similar to those used in a doctor's office and are not harmful to your child. Brain-wave activity and heart rate will be recorded for 2 minutes while your child will be asked to sit quietly (one minute with his/her eyes open and one minute with his/her eyes closed). Brain wave activity and heart rate will also be recorded while your child plays two games on the computer. The games will require your child to match cards and to respond to certain figures by pressing the space bar. Your child will also play a couple of flash card games, where s/he has to name what is on the card as fast as possible. After this procedure, the cap and patches will be removed and the gel will be washed from your child's hair with warm water and a clean washcloth. Finally, your child will be asked to match vocabulary words to pictures and name words that fall in a certain categories.

III. Risks

There is minimal risk associated with this research project. The brainwave procedures are similar to that done in a doctor's office and are not harmful. All brain-wave equipment is disinfected after each use. 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 perservatives that are used in everyday skin lotions.

IV. Benefits of This Research

There are no tangible benefits for you or your child. No promise or guarantee of benefits have been made to encourage you and your child to participate in this study. In a scientific sense, however, this research study will give developmental specialists more information about the development of memory and language skills during late childhood. Upon completion of this study, we will send you a letter briefly outlining the findings of this research.

V. Extent of Confidentiality

Information gathered for this study will be confidential and the information from each individual child will be identified by code number only. Information linking child name and code number will be kept in a card file and locked in a file drawer. Only Dr. Bell and her graduate Research Assistants will have access to the card file. Your child will be videotaped during the lab procedure. This allows us to go back at a later date and code your child's behaviors. Videotapes will identify children only by code number. Tapes will be stored in the research lab and will be accessible only to Research Assistants associated specifically with this research project. Dr. Bell will supervise the confidentiality of the videotapes. Tapes will be erased 5 years after publication of the results of this study. The research team will not give you direct information of how your child compares with any of the other children participating in this study.

VI. Compensation

You will not be compensated for your participation in the research. However, your child will receive a gift card for participation in the laboratory visit for this research study.

VII. Freedom to Withdraw

You may withdraw your child from participation in the lab visit portion of this research study at any time without penalty. Your child will still receive the gift card.

Approval of Research

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at VPI&SU and by the Department of Psychology at Virginia Tech.

IX. Parent's Responsibilities

none

X. Parent's Permission

I have read and understand the Informed Consent and conditions of this research study. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for my child to participate in this project. I understand that I may withdraw from participation 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) Martha Ann Bell, PhD
   Investigator, Associate Professor of Psychology, 231-2546
2) Denise R. Adkins
   Co-investigator, Graduate Student of Psychology, 231-2320
3) David W. Harrison, PhD
   Chair, Psychology Department Human Subjects Committee, 231-4422
4) David Moore, PhD
   Chair, IRB, CVM Phase II 231-4991

Appendix D - Child Assent Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Participant Consent Form

Title of Project: "Cognitive Development in Late Childhood"
Investigators: Martha Ann Bell, Ph.D., Denise R. Adkins

I. Purpose of this Research

You are invited to help us with a research project to learn about the way your brain waves and heart look when you play certain games.

II. Procedures

First, you will wear a cap that looks like a swim cap on your head and sticky patches on your back. We will put some gel through the little holes on the cap. This allows us to measure your brain waves and heart rate. While we put the gels in your cap, you will read and answer a few questions. After that, you will be asked to sit quietly and still for one minute with your eyes closed and one minute with your eyes open. Then, you will play a couple of games on the computer and a couple of flash card games. Then, we will take off the cap and patches and wipe the gel out of your hair. Finally, you will play a couple of word games.

III. Risks

You will get some gel in your hair, but we will wash it out when you are finished playing the games.

V. Benefits of This Research

You will get to help us understand the way that your brain waves and heart are related to the different ways children think when they play these games.

V. Extent of Confidentiality

We won't use your name when we report the results of this study.

VII. Compensation

We will give you a $10 gift card to Books-a-Million for participating in the study.

VIII. Freedom to Withdraw

You are free to withdraw at any time.

Approval of Research

Virginia Tech approved this research.

X. Participant's Responsibilities

We will ask that you sit still with your eyes open for one minute and closed for one minute. Also, we will ask you to answer some questions and play computer, flash card, and word games.

X. Participant's Permission

I have read and understand this form. I have asked any questions that I had and agree to participate in this study. I understand that I can quit at any time I want and will not be penalized. I understand that I will get a copy of this form.

______________________________________ ____________________________
Signature Date

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

1) Martha Ann Bell, PhD
    Investigator, Associate Professor of Psychology, 231-2546
2) Denise R. Adkins
    Co-investigator, Graduate Student of Psychology, 231-2320
3) David W. Harrison, PhD
    Chair, Psychology Department Human Subjects Committee, 231-4422
4) David Moore, PhD
    Chair, IRB, CVM Phase II 231-4991

Early Adolescent Temperament Questionnaire - Revised
Parent Report

Directions

On the following pages you will find a series of statements that people might use to describe their child. The statements refer to a wide number of activities and attitudes.

For each statement, please circle the answer which best describes how true each statement is for your child. There are no best answers. People are very different in how they feel about these statements. Please circle the first answer that comes to you.

You will use the following scale to describe how true or false a statement is about your child:

Circle number:	**If the statement is:**
1	Almost always untrue of your child
2	Usually untrue of your child
3	Sometimes true, sometimes untrue of your child
4	Usually true of your child
5	Almost always true of your child

NOTE: Please make certain to answer all questions on BOTH SIDES of the pages.

Please tell us:

Your child's date of birth: ____________

Your child's gender: M / F

Family ID code _________(please leave blank)

Your son or daughter:	Almost always untrue	Usually untrue	Sometimes true, sometimes untrue	Usually true	Almost always true
1) Worries about getting into trouble.	1	2	3	4	5
2) When angry at someone, says thing s/he knows will hurt that person's feelings.	1	2	3	4	5
3) Has a hard time finishing things on time.	1	2	3	4	5
4) Thinks traveling to Africa or India would be exciting and fun.	1	2	3	4	5
5) If having a problem with someone, usually tries to deal with it right away.	1	2	3	4	5
6) Has a hard time waiting his/her turn to speak when excited.	1	2	3	4	5
7) Often does not seem to enjoy things as much as his/her friends.	1	2	3	4	5
8) Opens presents before s/he is supposed to.	1	2	3	4	5
9) Would be frightened by the thought of skiing fast down a steep slope.	1	2	3	4	5
10) Feels like crying over very little on some days.	1	2	3	4	5
11) If very angry, might hit someone.	1	2	3	4	5
12) Likes taking care of other people.	1	2	3	4	5
13) Likes to be able to share his/her private thoughts with someone else.	1	2	3	4	5
14) Usually does something fun for awhile before starting her/his homework, even though s/he is not supposed to.	1	2	3	4	5
15) Finds it easy to really concentrate on a problem.	1	2	3	4	5
16) Thinks it would be exciting to move to a new city.	1	2	3	4	5
17) When asked to do something, does it right away, even if s/he doesn't want to.	1	2	3	4	5
18) Would like to be able to spend time with a good friend every day.	1	2	3	4	5
19) Tends to be rude to people s/he doesn't like.	1	2	3	4	5
20) Is annoyed by little things other kids do.	1	2	3	4	5
21) Gets very irritated when someone criticizes her/him.	1	2	3	4	5
22) When interrupted or distracted, forgets what s/he was about to say.	1	2	3	4	5
23) Is more likely to do something s/he shouldn't do the more s/he tries to stop her/himself.	1	2	3	4	5

24) Enjoys exchanging hugs with people s/he likes.	1	2	3	4	5
25) Tends to try to blame mistakes on someone else.	1	2	3	4	5
26) Is sad more often than other people realize.	1	2	3	4	5
Your son or daughter:	Almost always untrue	Usually untrue	Sometimes true, sometimes untrue	Usually true	Almost always true
27) Can generally think of something to say, even with strangers.	1	2	3	4	5
28) Wouldn't be afraid to try a risky sport like deep sea diving.	1	2	3	4	5
29) Expresses a desire to travel to exotic places when s/he hears about them.	1	2	3	4	5
30) Worries about our family when s/he is not with us.	1	2	3	4	5
31) Gets irritated when I will not take her/him someplace s/he wants to go.	1	2	3	4	5
32) Slams doors when angry.	1	2	3	4	5
33) Is hardly ever sad, even when lots of things are going wrong.	1	2	3	4	5
34) Would like driving a racing car.	1	2	3	4	5
35) Has a difficult time tuning out background noise and concentrating when trying to study.	1	2	3	4	5
36) Usually finishes her/his homework before it's due.	1	2	3	4	5
37) Likes it when something exciting and different happens at school.	1	2	3	4	5
38) Usually gets started right away on difficult assignments.	1	2	3	4	5
39) Is good at keeping track of several different things that are happening around her/him.	1	2	3	4	5
40) Is energized by being in large crowds of people.	1	2	3	4	5
41) Makes fun of how other people look.	1	2	3	4	5
42) Doesn't criticize others.	1	2	3	4	5
43) Wants to have close relationships with other people.	1	2	3	4	5
44) Is shy.	1	2	3	4	5
45) Gets irritated when s/he has to stop doing something s/he is enjoying.	1	2	3	4	5
46) Usually puts off working on a project until it is due.	1	2	3	4	5

47) Is able to stop him/herself from laughing at inappropriate times.	1	2	3	4	5
48) Is afraid of the idea of me dying or leaving her/him.	1	2	3	4	5
49) Is often in the middle of doing one thing and then goes off to do something else without finishing it.	1	2	3	4	5
50) Is not shy.	1	2	3	4	5
Your son or daughter:	Almost always untrue	Usually untrue	Sometimes true, sometimes untrue	Usually true	Almost always true
51) Is quite a warm and friendly person.	1	2	3	4	5
52) Sometimes seems sad even when s/he should be enjoying her/himself like at Christmas, or on a trip.	1	2	3	4	5
53) Doesn't enjoy playing softball or baseball because s/he is afraid of the ball.	1	2	3	4	5
54) Likes meeting new people.	1	2	3	4	5
55) Feels scared when entering a darkened room at night.	1	2	3	4	5
56) Wouldn't want to go on the frightening rides at the fair.	1	2	3	4	5
57) Hates it when people don't agree with him/her.	1	2	3	4	5
58) Gets very frustrated when s/he makes a mistake in her/his school work.	1	2	3	4	5
59) Is usually able to stick with his/her plans and goals.	1	2	3	4	5
60) Pays close attention when someone tells her/him how to do something.	1	2	3	4	5
61) Is nervous being home alone.	1	2	3	4	5
62) Feels shy about meeting new people.	1	2	3	4	5

Appendix F - General Information Questionnaire

Child Development Project

General Information Questionnaire

Child ID number _____________

Date of visit _________________

1. Sex of child: M F

2. Date of birth __________________

3. Weight at birth _________________

4. Birth order: Your child was born _____ out of _____ siblings

5. What was the expected due date? _____________

6. Did your child receive any oxygen at birth or soon thereafter?
   _________ no
   _________ yes

7. Has your child experienced any serious illness or problems in development?
   _________ no
   _________ yes-----brief explanation___________________________________

8. Has your child ever had any neurological problems, such as epilepsy, or seizures of any kind?
   ___________no
   ___________yes-----brief explanation _________________________________

9. Has your child received any long term medication?
   __________ no
   __________ yes-----brief explanation______________________________

10. Is your child ill or on any medications now?
    ___________no
    ___________yes------brief explanation ___________________________________

11. Has your child shown an allergic reaction to anything?
    ___________no
    ___________yes-----brief explanation__________________________________

12. Has your child ever had any skin irritations?
    ___________ no
    ___________yes

13. Age of parents <u>at child's birth</u>:
    mother_______
    father ________

14. Background information of parents:

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

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

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

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

15. Highest level of education completed (please note any "in progress"):

mother _____elementary school
_____Jr.high/middle school
_____GED
_____high school
_____technical school
_____college
_____graduate school

father _____elementary school
_____Jr. high/middle school
_____GED
_____high school
_____technical school
_____college
_____graduate school

16. Which hand does your child prefer to use for each of these activities?
Please put **R** (right hand), **L** (left hand), or **E** (either hand).

a. Writing _______
b. Drawing _______
c. Throwing _______
d. Cutting with scissors _______
e. Brushing teeth _______
f. Using a knife (without fork) _______
g. Eating with a spoon _______
j. Opening jar (which hand is on lid?) _______

* * * *

k. Which foot is preferred to kick with? _______
l. Which eye is used when using only one? _______

17. What was the last grade your child successfully completed? __________

18. How old was your child on his/her last birthday? _________

19. Is your child color blind? ____Yes ____No

20. Is anyone in the child's family color blind? ___Yes ____No If so, what is the relation of that person to the child? ___________________________

Early Adolescent Temperament Questionnaire - Revised
Short Form

Directions

On the following page you will find a series of statements that people might use to describe themselves. The statements refer to a wide number of activities and attitudes.

For each statement, please circle the answer that best describes how true each statement is **for you**. There are no best answers. People are very different in how they feel about these statements. Please circle the first answer that comes to you.

You will use the following scale to describe how true or false a statement is about you:

Circle number:	If the statement is:
1	Almost always untrue of you
2	Usually untrue of you
3	Sometimes true, sometimes untrue of you
4	Usually true of you
5	Almost always true of you

NOTE: Please make certain to answer all questions on BOTH SIDES of the page.

Please tell us:

Your date of birth: ___________

Your gender: M / F

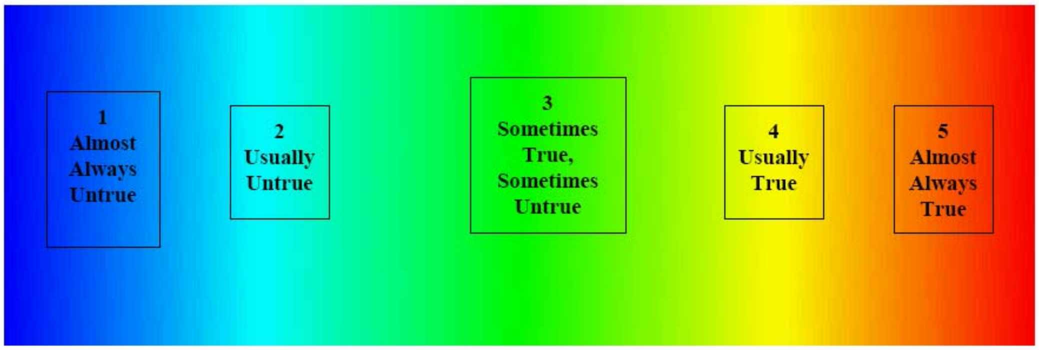
Family ID code: __________

How true is each statement for you?	Almost always untrue	Usually untrue	Sometimes true, sometimes untrue	Usually true	Almost always true
1) It is easy for me to really concentrate on homework problems.	1	2	3	4	5
2) I feel pretty happy most of the day.	1	2	3	4	5
3) I think it would be exciting to move to a new city.	1	2	3	4	5
4) I like to feel a warm breeze blowing on my face.	1	2	3	4	5
5) If I'm mad at somebody, I tend to say things that I know will hurt their feelings.	1	2	3	4	5
6) I notice even little changes taking place around me, like lights getting brighter in a room.	1	2	3	4	5
7) I have a hard time finishing things on time.	1	2	3	4	5
8) I feel shy with kids of the opposite sex.	1	2	3	4	5
9) When I am angry, I throw or break things.	1	2	3	4	5
10) It's hard for me not to open presents before I’m supposed to.	1	2	3	4	5
11) My friends seem to enjoy themselves more than I do.	1	2	3	4	5
12) I tend to notice little changes that other people do not notice.	1	2	3	4	5
13) If I get really mad at someone, I might hit them.	1	2	3	4	5
14) When someone tells me to stop doing something, it is easy for me to stop.	1	2	3	4	5
15) I feel shy about meeting new people.	1	2	3	4	5
16) I enjoy listening to the birds sing.	1	2	3	4	5
17) I want to be able to share my private thoughts with someone else.	1	2	3	4	5
18) I do something fun for a while before starting my homework, even when I’m not supposed to.	1	2	3	4	5
19) I wouldn't like living in a really big city, even if it was safe.	1	2	3	4	5
20) It often takes very little to make me feel like crying.	1	2	3	4	5
21) I am very aware of noises.	1	2	3	4	5
22) I tend to be rude to people I don't like.	1	2	3	4	5
23) I like to look at the pattern of clouds in the sky.	1	2	3	4	5
24) I can tell if another person is angry by their expression.	1	2	3	4	5

25) It bothers me when I try to make a phone call and the line is busy.	1	2	3	4	5
26) The more I try to stop myself from doing something I shouldn't, the more likely I am to do it.	1	2	3	4	5
27) I enjoy exchanging hugs with people I like.	1	2	3	4	5
28) Skiing fast down a steep slope sounds scary to me.	1	2	3	4	5
29) I get sad more than other people realize.	1	2	3	4	5
30) If I have a hard assignment to do, I get started right away.	1	2	3	4	5
31) I will do most anything to help someone I care about.	1	2	3	4	5
32) I get frightened riding with a person who likes to speed.	1	2	3	4	5
How true is each statement for you?	**Almost always untrue**	**Usually untrue**	**Sometimes true, sometimes untrue**	**Usually true**	**Almost always true**
33) I like to look at trees and walk amongst them.	1	2	3	4	5
34) I find it hard to shift gears when I go from one class to another at school.	1	2	3	4	5
35) I worry about my family when I'm not with them.	1	2	3	4	5
36) I get very upset if I want to do something and my parents won't let me.	1	2	3	4	5
37) I get sad when a lot of things are going wrong.	1	2	3	4	5
38) When trying to study, I have difficulty tuning out background noise and concentrating.	1	2	3	4	5
39) I finish my homework before the due date.	1	2	3	4	5
40) I worry about getting into trouble.	1	2	3	4	5
41) I am good at keeping track of several different things that are happening around me.	1	2	3	4	5
42) I would not be afraid to try a risky sport, like deep-sea diving.	1	2	3	4	5
43) It's easy for me to keep a secret.	1	2	3	4	5
44) It is important to me to have close relationships with other people.	1	2	3	4	5
45) I am shy.	1	2	3	4	5

46) I am nervous of some of the kids at school who push people into lockers and throw your books around.	1	2	3	4	5
47) I get irritated when I have to stop doing something that I am enjoying.	1	2	3	4	5
48) I wouldn't be afraid to try something like mountain climbing.	1	2	3	4	5
49) I put off working on projects until right before they're due.	1	2	3	4	5
50) When I'm really mad at a friend, I tend to explode at them.	1	2	3	4	5
51) I worry about my parent(s) dying or leaving me.	1	2	3	4	5
52) I enjoy going places where there are big crowds and lots of excitement.	1	2	3	4	5
53) I am not shy.	1	2	3	4	5
54) I am quite a warm and friendly person.	1	2	3	4	5
55) I feel sad even when I should be enjoying myself, like at Christmas or on a trip.	1	2	3	4	5
56) It really annoys me to wait in long lines.	1	2	3	4	5
57) I feel scared when I enter a darkened room at home.	1	2	3	4	5
58) I pick on people for no real reason.	1	2	3	4	5
59) I pay close attention when someone tells me how to do something.	1	2	3	4	5
60) I get very frustrated when I make a mistake in my school work.	1	2	3	4	5
How true is each statement for you?	**Almost always untrue**	**Usually untrue**	**Sometimes true, sometimes untrue**	**Usually true**	**Almost always true**
61) I tend to get in the middle of one thing, then go off and do something else.	1	2	3	4	5
62) It frustrates me if people interrupt me when I'm talking.	1	2	3	4	5
63) I can stick with my plans and goals.	1	2	3	4	5
64) I get upset if I'm not able to do a task really well.	1	2	3	4	5
65) I like the crunching sound of autumn leaves.	1	2	3	4	5

Appendix H – Temperament Questionnaire Answer Guide



Appendix I – Latin-square Design

Group A	Cgng	wcst	cw	fruit
Group B	Wcst	fruit	cgng	cw
Group C	Cw	cgng	fruit	wcst
Group D	Fruit	cw	wcst	cgng

Note: cgng = Counting Go/No-go
wcst = WCST-64
cw = color-word Stroop
fruit = fruit Stroop

Group A = participants 1, 5, 9, 13, 17, 21, 25, 29, 33, 37
Group B = participants 2, 6, 10, 14, 18, 22, 26, 30, 34, 38
Group C = participants 3, 7, 11, 15, 19, 23, 27, 31, 35, 39
Group D = participants 4, 8, 12, 16, 20, 24, 28, 32, 36, 40

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Professional Experience:

2005-present	Graduate Assistant, Developmental Sciences Initiative, Virginia Tech
Fall 2004	Graduate Research Assistant, Graduate School, Virginia Tech
2002-present	Research Assistant, Developmental Cognitive Neuroscience Lab, Virginia Tech
2002-present	Graduate Teaching Assistant, Department of Psychology, Virginia Tech

Courses Taught:

Course Title	***Semester Taught***	***Overall Evaluation (out of 4.0)***
Cognitive Psychology	Fall 2005	4.0
Principles of Psychological Research	Summer 2005	3.8
Developmental Psychology	Spring 2005	3.9 ; 3.8
Developmental Psychology	Fall 2004	3.8
Developmental Psychology	Summer 2004	3.8
Advanced Developmental Lab	Spring 2004	3.8 ; 3.9
Advanced Developmental Lab	Fall 2003	3.7 ; 3.6
Introductory Psychology Recitation	Spring 2003	3.9 ; 3.7 ; 3.9
Introductory Psychology Recitation	Fall 2002	3.9 ; 3.8 ; 3.9

Mentoring/Advising/Outreach:

- Guest lectured for Social, Introductory, and Advanced Developmental courses
- Served as a resource for students in graduate/career/major choices
- Aided fellow graduate students in course preparation
- Wrote letters of recommendation for students applying for graduate school
- Wrote letters of recommendation for students applying for jobs
- Annual presentations for Cave Spring High School Psychology Classes Virginia Tech (2003; 2004)
- Attended practice proposals, defenses, and presentations for fellow graduate students and undergraduates
- Trained numerous undergraduate students on lab procedures
- Supervised a McNair Scholar project
- Supervised an undergraduate research project
- Trained two incoming graduate students in lab procedures and task administration
- Volunteer Assistant at Society for Research in Child Development (2005)
- Volunteer at International Society for Developmental Psychobiology (2005)

Professional Development Efforts:

- Society for the Teaching of Psychology (STP): American Psychological Association (APA) Division 2 Graduate Student Teaching Association (GSTA) member (2005)
- Future Professoriate Graduate Certificate from Virginia Tech (Fall 2005)

Attendance at Professional Development Workshops Sponsored by Virginia Tech:

- Balancing Work and Family
- Elements of Course Design
- Rhetorical Sensitivity
- Lecture Preparation
- Grading Issues
- Creating PDF Files for Instruction
- Diggs Scholar's Q&A Panel on Teaching
- Library Resources for Teaching and Research
- Professional Ethics in Teaching and Research
- Online Student Ratings of Instruction Tool: Formative Evaluations
- Connecting With Students Through Online Interaction
- Motivating Your Students: Strategies for Design and Implementation
- Students as Audience: Matching Your Message and Delivery to Their Needs and Expectations
- Creating PowerPoint Presentations and Adding Multimedia Enhancements
- Completed online NIH Human Subjects Training course

Honors/Awards:

- Virginia Tech Outstanding Graduate Teaching Excellence Award (2006)
- Phi Kappa Phi Honor Society member (2005)
- Virginia Tech Department of Psychology Nominee for APA Dissertation Research Award (2006)
- NIH travel grant to International Society for Developmental Psychobiology (Fall 2005)
- Virginia Tech Clinical Child Research Fund Award (Summer 2004)

- Virginia Tech Graduate Student Association Travel Fund Award (Spring 2004; Spring 2005; Fall 2005)
- Virginia Tech Graduate Research Development Project Award (Spring 2003; Fall 2005)
- Bustard Graduate Scholarship from Averett University (Fall 2002)

Publications:

Adkins, D.R. (2003). Introduction to Development. In P.K. Lehman, C. Dula, J.W. Finney (Eds.), *Introductory Psychology Recitation Reader* (pp. 139-140). Boston, MA: McGraw Hill.

Adkins, D.R. & Bell, M.A. (under revision). Individual differences in spatial memory performance at 12 months of age: Contributions from walking experience and brain electrical activity. *Developmental Psychobiology*.

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

Manuscripts in Progress:

Adkins, D.R., & Bell, M.A. (in preparation). Individual differences in attention in middle childhood.

Adkins, D.R., Wolfe, C.D., & Bell, M.A. (in preparation). The development of working memory and inhibitory control from early to middle childhood.

Conference Presentations:

Oral Presentation:

Adkins, D.R. (2005, November). A brain-behavior investigation of attention in middle childhood. NIH travel awardee oral presentation given at International Society for Developmental Psychobiology, Washington, D.C.

Poster Presentations:

Adkins, D.R. & Bell, M.A. (2005, November). An investigation of attention in middle childhood. Poster presented at International Society for Developmental Psychobiology, Washington, D.C.

Adkins, D.R. & Bell, M.A. (2005, August). Regulatory Processes and the Interactions between Emotion and Cognition. Poster presented at the American Psychological Association, Washington, D.C.

Adkins, D.R., Clory, T., & Bell, M.A. (2005, April). Individual Differences in Spatial Memory at 12 Months of Age: Contributions from Walking Experience and Brain Electrical Activity. Poster presented at the Society for Research in Child Development, Atlanta, Georgia.

Adkins, D.R., Clory, T., & Bell, M.A. (2004, May). Associations between locomotor experience and spatial search performance in 12-month-old infants. Poster presented at the International Conference on Infant Studies, Chicago, Illinois.

Conference Membership:

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- International Society for Developmental Psychobiology (ISDP-----since 2005)
- International Society on Infant Studies (ISIS-----since 2003)
- Society for Research in Child Development (SRCD-----since 2003)

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