Individual Differences in Inhibitory Control Skills at Four Years of Age

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ABSTRACT

Inhibitory Control (IC), a vital facet of childhood development, involves the ability to suppress a dominant response, as well as the ability to suppress irrelevant thoughts and behaviors. This ability emerges during the first year of life and develops rapidly during the preschool years. A variety of tasks have been developed to measure IC in this age group and, recently, research has demonstrated important differences in task performance according to various distinctions among these tasks. One under-researched distinction is that of whether an IC task requires the child to give a verbal or a motoric response. Therefore, the purpose of this study was to examine, in 4-year-old children, the differences and similarities among IC tasks requiring either a verbal or a motoric response. Differences were explored with respect to the contributions to verbal and motoric IC performance of language, intelligence, temperament, and frontal encephalography, as well as with respect to social and school readiness outcomes.

IC was best described by a two-component model, distinguishing verbal and motoric IC. Both baseline and task electrophysiology contributed to task performance in the verbal Yes-No task as well as the motoric IC composite. Language and intelligence, too, were associated with both verbal and motoric IC, although nonverbal intelligence was less strongly correlated with verbal IC than it was with motoric IC. All laboratory measures of IC related to parent report of children's IC as well as to other parent-reported temperament scales and factors. Children's verbal and motoric IC were associated, too, with children's social development, surprisingly showing the most consistent associations with social inhibition. Asocial behavior positively correlated more strongly with motoric IC than with verbal IC. Children's laboratory IC positively correlated with their school readiness, even when controlling for their intelligence although children's emergent literacy more positively related to their motoric, rather than verbal, IC. An interaction of intelligence and IC contributed to social variables, but not to school readiness.

This research supports the important distinction between verbal and motoric IC, and demonstrates the utility of including an array of measures of both in early childhood research.

Dedication

To Laura, Jeremiah, and Lois, my chosen family. Thank you for all that you do. I love you.

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Chapter 1

Introduction

Inhibitory Control (IC), the ability to inhibit dominant, automatic responses when necessary (Miyake, Friedman, Emerson, Witzki, & Howerter, 2000), is an executive function vital to young children's development. Inhibitory abilities translate to important practical skills in children's day-to-day lives. For example, IC helps children to raise their hand in the classroom before speaking (Ponitz, McClelland, Matthews, & Morrison, 2009) and to avoid using physical aggression with peers who stand in the way of their goals (Rhoades, Greenberg, & Domitrovich, 2009). IC also helps children to control themselves verbally. For example, it is IC that prevents children from sharing inappropriate information, and that may also help bilingual children to inhibit knowledge from other languages in order to focus on the language relevant to the conversation at hand (Carlson & Meltzoff, 2008).

Because of the applicability of inhibitory processes, it is not surprising that IC relates to other important aspects of children's development. For example, preschoolers who performed well on a delay of gratification paradigm requiring them to resist a tempting treat for a larger later reward were better able to get along with their peers and to manage friendships ten years later (Mischel, Shoda, & Peake, 1988). Children's regulation also protects them from disruptive social behaviors (Hughes, White, Sharpen, & Dunn, 2000) as well as from internalizing and externalizing problem behaviors, both concurrently and longitudinally (Caspi, Henry, McGee, Moffitt, & Silva, 1995; Eisenberg et al., 2009; Kochanska & Knaack, 2003; Newman, Caspi, Moffitt, & Silva, 1997), even when controlling for relevant social risk variables (Olson, Sameroff, Kerr, Lopez, & Wellman, 2005).

IC is also important to children's school functioning. Children who are best able to inhibit their emotions and behaviors are viewed by their teachers as being more ready to begin formal schooling than are their less regulated peers (Denham, 2006). Those same regulated children are better able to sit still for extended periods of time, to pay attention, and to process detailed information that aids in learning (Coplan, Barber, & Lagace Seguin, 1999; Lemerise & Arsenio, 2000; NICHD Early Child Care Research Network, 2003). They also enjoy school more and have higher school competence (Fabes, Martin, Hanish, Anders, & Madden Derdich, 2003; Valiente, Lemery-Chalfant, & Castro, 2007). In fact, children's regulation predicts their mathematics and reading abilities (Blair & Razza, 2007), and the relation to mathematics achievement remains strong in preschool (Bull, Espy, & Wiebe, 2008; Espy et al., 2004), kindergarten (Ponitz et al., 2009; Welsh, Nix, Blair, Bierman, & Nelson, 2010) and at 7 years of age (Bull & Scerif, 2001).

Because of the notable effects of IC, it is important to look at its development in early childhood. For this reason, I have conducted an investigation that focuses on characteristics of two types of children's IC when children are 4 years old and, thus, in the midst of rapid development.

IC Development

Inhibitory abilities emerge during the first year of life (Cuevas, Swingler, Bell, Marcovitch, & Calkins, 2012; Diamond 1990a, 1990b). This emergence is thought to be related to the development of the anterior attention system at the same time (Ruff & Rothbart, 1996). As such, even young infants show some evidence of IC. For example, infants as young as 4 months of age are able to inhibit the prepotent response of a lateral saccade, even when they are not able to combine this response with the subdominant response of a saccade to the opposite side (Johnson, 1995). This subdominant response does not emerge until 12 to 18 months (Scerif, Cornish, Wilding, Driver, & Karmilloff-Smith, 2004).

IC abilities continue to develop throughout infancy and toddlerhood, although it is not until the preschool-aged years that this development begins to occur more rapidly (Carlson, 2005). For example, performance on the Grass-Snow task (Carlson & Moses, 2001), which requires children to point to a green piece of paper when an experimenter says, “snow”, and to point to a white piece of paper when the experimenter says, “grass”, improves from a 40% pass rate at 3 years of age to 84% for older 4 year olds, with passing being defined as responding correctly on 75% of trials (Carlson, 2005; See Table 1 for a description of all tasks described in this document.). Very similarly, performance on the Yes-No task (Kraybill & Bell, 2012; Wolfe & Bell, 2004, 2007), which requires children to say “yes” to an experimenter’s head shakes and “no” to an experimenter’s head nods, improves from 42% at 3.5 years of age to 61% at 4 years and 66% at 4.5 years (Wolfe & Bell, 2007). Performance on the Tapping Task, which requires children to tap twice with a wooden dowel when an experimenter taps one and vice versa, also rapidly improves in this time frame, from 64% accuracy in 3.5-year-olds to 88% in 5-year-olds (Diamond & Taylor, 1998).

Perhaps the most dramatic example of the rapid development of IC in early childhood involves the Day-Night task (Gerstadt, Hong, & Diamond, 1994), which requires children to say “day” when presented with a picture of a moon and stars on a dark background and to say “night” when presented with a picture of a sun on a white background. Researchers initially intended to use the task to measure IC in children as young as 3 years of age, but children of this age either failed the pretest or refused to play at such a rate that data collection was discontinued in this age group (Gerstadt et al., 1994). Yet, 3.5-year-olds can complete the same task with 72% accuracy (Gerstadt et al., 1994).

Following this period, IC continues to develop, but not at the same rapid pace as during the preschool years. Many of the aforementioned tasks quickly hit ceiling effects shortly after the preschool-aged period, making it difficult to detect any improvement in performance. For example, performance on the above-mentioned Tapping Task, which was 88% at 5 years of age, improves only to 89% in 5.5-year-olds, and it stagnates between 94% and 98% between ages 6 and 7 years (Diamond & Taylor, 1998). However, the slowed pace of growth throughout the rest of childhood also fits with brain-based evidence. The frontal lobes, the area of the brain thought to support IC abilities, develop the most rapidly during infancy, and then experience a growth spurt between about 4 and 7 years of age (Luria, 1973; Thatcher, 1992). Thus, at the completion of this growth spurt, inhibitory abilities develop at a much slower pace.

Because 4-year-old children are at the cusp of this frontal lobe growth spurt as well as in the midst of rapid development in IC performance, and because their performance on IC tasks is subject to neither ceiling nor floor effects at this age, 4-year-old children are ideal research participants for research on IC.

Measuring Different Types of IC

In order to determine children's IC abilities, researchers must first find a way to measure these abilities. Ideally, a task of IC should capture a range of individual differences in performance without being subject to floor and ceiling effects and, of course, the task should measure, as purely as possible, children's IC itself. Unfortunately, there exists no task capable of measuring pure inhibition, as each task must measure inhibition of *something* (Friedman & Miyake, 2004). Furthermore, many tasks differ in the complexity of the way in which a child is expected to inhibit and in the emotional urges involved in inhibiting. As such, researchers have established a number of common categories of IC tasks based on the "something" that is being inhibited as well as on these other complexities of the tasks.

One categorization depends on the simplicity versus the complexity of a task (Garon, Bryson, & Smith, 2008). Simple inhibition tasks involve withholding a dominant response, whereas complex inhibition tasks require responding to a rule held in mind while inhibiting a prepotent response (Garon et al., 2008). A very similar, and more popular, distinction involves categorizing tasks according to whether they require inhibition under conditions of delay or under conditions of conflict (Carlson & Moses, 2001; Carlson, Moses, & Breton, 2002). Delay IC requires children, like in simple inhibition, to withhold, or to delay, the initiation of a dominant response (Carlson & Moses, 2001). For example, the gift delay task (Kochanska, Murray, Jacques, Koenig, & Vandegeest, 1996) requires children to wait, without peeking, while an experimenter wraps a gift in front of them. Thus the task taxes children to delay their dominant peeking response. In contrast, conflict IC tasks, much like complex IC tasks, require children to suppress a dominant response while performing a conflicting action (Carlson & Moses, 2001). For example, the Day-Night task, described earlier, requires children not only to withhold their prepotent response of naming the picture on the card (day), but to also perform the conflicting action of naming the card with its "silly" label (night). All of the tasks utilized in this study can be categorized as tasks of both complex and conflict IC.

Another popular distinction to arise in recent years is that of whether a task is "hot" or "cool". Zelazo and colleagues (Zelazo & Muller, 2002; Zelazo, Qu, & Muller, 2005) describe executive functions as being hot when they involve the regulation of affect and motivation and as being cool when the problems faced are more abstract and cognitive in nature. Hot and cool executive function tasks differ, too, in the brain areas associated with performance. Although hot executive functions are associated with the ventral and medial regions of the prefrontal cortex, cool executive functions are more closely associated with the dorsalateral prefrontal cortex (Zelazo & Muller, 2002). IC, as an executive function, is then subject to the same distinction, and researchers have begun to look at the differences in the risk factors associated with deficits in hot and cool IC (Geurts, Van der Oord, & Crone, 2006; Huijbregts, Warren, Sonneville, & Swaab-Barneveld, 2008). Examples of tasks of hot IC, those requiring children to overcome an affective or motivational component, include the Less is More task (Carlson, Davis, & Leach, 2005), which requires children to choose a smaller array of treats in order to later earn a larger array, and the aforementioned gift delay task. Meanwhile, all of the tasks that I have utilized in this study are believed to be cool, drawing upon children's ability to inhibit under conditions that are more abstract and less emotionally-charged.

I utilized tasks of complex, conflict, and cool IC, because, for the purposes of this study, I consider IC to be cognitive in nature, and as an executive function. By focusing on one side of each of these dichotomies, I am able to examine variations in IC tasks while controlling for differences that could arise due to differences in the side of the dichotomy on which these tasks fall. I have chosen to focus on tasks that could be considered complex/conflict, because I am interested in measuring IC under conditions in which children must initiate a subdominant action. I have chosen tasks which are also cool in nature, because I believe that the abstract nature of these tasks allows for better measurement of the cognitive nature of IC without variations that could be explained by emotion or motivation, as one may see in hot tasks.

It could be argued that the aforementioned dichotomies are not unique from one another, and that simple, delay, and hot tasks are equivalent and to be contrasted with the corresponding complex, conflict, and cool tasks. I have outlined above the overlapping definitions of simple/complex and delay/conflict IC. Though less intuitive, these distinctions also often overlap with the hot/cool distinction. Tasks requiring children to delay their prepotent responses (delay IC) often require them to overcome an affective or motivational component (hot IC). For example, the aforementioned gift delay task requires both delay and hot IC skills by requiring children to delay the very motivated response of opening a gift. The similar snack delay and marshmallow delay tasks also require both delay and hot IC skills as children delay the strong urge to eat the treats in front of them.

Conflict IC tasks, too, often overlap with cool IC tasks. Those tasks requiring children to suppress a dominant response while performing a conflicting action (conflict IC) are often abstract and cognitive in nature (cool IC). For example, the Day-Night, Yes-No, and Grass-Snow tasks outlined above all require children to respond with an action that conflicts with their prepotent response (conflict IC) to a problem that is relatively abstract in nature (cool IC). There are exceptions to this overlap. For example, the Less is More task described above requires children to provide a conflicting action (conflict IC) to the relatively affective prepotent response of choosing a large array of treats (hot IC). However, these exceptions are rare.

With the wide array of tasks available in early childhood IC batteries, it is surprising that the few distinctions that have been made among tasks that are so similar to one another. Therefore, the purpose of my investigation is to examine children's performance on tasks that have been categorized by a more unique distinction, that of verbal versus motoric IC.

A Unique New Distinction

This more novel distinction of verbal versus motoric IC involves discriminating between whether a task requires children to regulate their impulses to speak or to regulate those to move their bodies, respectively. Examples of those verbal IC tasks, requiring children to override their prepotent verbal response to instead initiate a subdominant verbal response, include the aforementioned Day-Night and Yes-No tasks. The Silly Sounds Stroop (Willoughby, Wirth, & Blair, 2011), also calls on verbal IC, requiring children to override the dominant response to "meow" or "woof" in response to a picture of a cat or dog, respectively, in order to instead act upon the subdominant response to make the opposite sound. In contrast, examples of motoric IC tasks, those tasks requiring children to overcome prepotent responses to move their bodies, include the Tapping Task and Grass-Snow task, described above. The Hand Game (Hughes, 1996; 1998; 1998b; Luria, Pribram, & Homskaya, 1964) is a task of motoric IC as well, requiring children to overcome the urge to imitate the hand gesture of an experimenter in order to make a different gesture. It should be acknowledged that verbal IC does involve controlling the muscles of the mouth and throat, so it could be argued that verbal IC involves a motoric component. However, for the purpose of this study, I define motoric IC as control of other bodily movements, rather than control of the movements necessary for verbal responses. Thus all motoric IC is nonverbal in nature, involving the control of bodily muscles outside of the mouth and throat.

This distinction between verbal and motoric task demands is popular in literature on intelligence, so much so that many intelligence tests, such as the Wechsler Adult Intelligence Scale (Wechsler, 2008) and the Stanford-Binet Intelligence Scales (Thorndike, Hagen, & Sattler, 1986) include separate scales for questions that draw upon verbal demands and those that call upon nonverbal demands. By borrowing a variation of the verbal versus nonverbal task distinction, the verbal versus motoric task distinction, from the intelligence literature, psychologists interested in IC have a unique way of classifying task demands that may give insight into the contributions to, and outcomes of, IC tasks of different natures.

Indeed, Luria, the creator of the Hand Game task, and colleagues briefly distinguished verbal and nonverbal regulation of behavior in adults with damage to their frontal lobes (Luria, et al., 1964). The team found that one subject, although able to follow simple verbal instructions with firm instructions to complete a task (such as raising her hand) only once, struggled when instructions required her to execute similar movements for a certain number of times (such as shaking her hand three times). Even though she could repeat the experimenter's instructions, she had difficulty stopping her movements after the prescribed number of hand-shakes. The authors interpreted this to mean that the nonverbal regulation (viewed as actual hand shakes) was more difficult than the verbal regulation of behavior (viewed as repetition of instructions). Although the idea of differences among verbal and nonverbal behavior was introduced decades ago, the topic has not been explored in depth.

Recently, however, researchers have proposed that cognitive and motor development may be related, and have supported the claim with neurological evidence supporting the interrelations of the cerebellum and the prefrontal cortex, which underlie motor and cognitive functioning, respectively (Diamond, 2000). As such, research has begun to explore the effects of exercise on executive function. The gerontological literature has proposed and found much support for the Executive Function Hypothesis, which proposes that exercise can improve executive functions even more so than it improves other cognitive processes (Churchill, Galvez, Colcombe, Swain, Kramer, & Greenough, 2002; Hall, Smith & Keele, 2001; Kramer et al., 1999). The benefits of exercise on executive function are also present in childhood (Davis et al., 2007, 2011; Tomporowski, Davis, Miller, & Naglieri, 2008).

However, others have shown that not all exercise is equally beneficial to executive functions. For example, adolescent juvenile delinquents assigned to “modern marital arts”, which emphasizes only physical activity, showed fewer executive function gains as compared to those assigned to traditional tae kwon do, which emphasizes character development in addition to physical conditioning (Trulson, 1986). For this reason, it has been proposed that the most beneficial executive function training involves both exercise and mindfulness (Diamond, 2012; Diamond & Lee, 2011). By investigating motoric IC, the proposed study examines the characteristics of this mindful movement of the body as compared to the mindful control of words.

Because the verbal/ motoric IC task distinction focuses on whether children regulate their words or their bodily movements, it is unique from the popular simple/complex, conflict/delay, and hot/cool distinctions. In other words, verbal IC tasks can also be either hot or cool (or simple or complex, or conflict or delay) in nature, as can motoric IC tasks. For example, the Grass-Snow, Hand Game, and Tapping Tasks are all motoric IC tasks that are also tasks of complex, conflict, and cool IC, and the Marshmallow Delay, Tongue Task, and Gift Delay are all motoric IC tasks that are instead simple, delay, and hot in IC nature. Similarly Yes-No, Day-Night, and the Silly Sounds Stroop are all verbal IC tasks that are all also complex, conflict, and cool IC, whereas requiring children to delay telling an exciting secret would require verbal IC and would be instead simple, delay, and hot in nature.

Although not phrased as such, a few studies have found differences between verbal and motoric IC task performance. In college students, performance on the antisaccade task, which requires a motoric response, but not the Stroop task, which requires a verbal response, related to list recall (Friedman & Miyake, 2004). It is difficult to find investigations in early childhood that report data on individual tasks rather than on task composites, although a few key studies do report on differences between individual tasks that could be described as verbal and those that could be described as motoric. For example, Diamond and colleagues found that children perform better on Luria's Tapping Task, a task for motoric IC, than on the verbal IC Day-Night task, and that they were able to sustain better performance on this task for more trials, but that it took longer for children to understand the rules of the task (Diamond & Taylor, 1996). Furthermore, Rhoades and colleagues (2009) found that Luria's peg Tapping Task, was a more robust predictor of child social-emotional factors than was Day-Night in disadvantaged 4- and 5-year-old children, and Utendale and colleagues (2011) found that longer response latencies on the Tapping Task, but not Day-Night, related to externalizing problems in 4- and 6-year-old boys.

Furthermore, recent work has shown differences in how verbal and motoric IC tasks relate to electrophysiology, temperament, and language in 3-year-old children (Watson & Bell, 2013). Performance on the motoric IC task, the Hand Game, was predicted by each of these components, but performance on the verbal IC task, Day-Night, was not. Children, like in Diamond's investigation of the Tapping Task, also struggled with understanding the rules of the Hand Game more so than they did the rules of other tasks. However, this research was limited by children's poor performance on tasks of verbal IC. Therefore, more work is necessary to determine the fundamental differences in contributions to children's performance on verbal and motoric IC tasks in a group of children capable of performing well on both types of tasks. This study accomplishes this by testing 4-year-old children's inhibitory abilities with tasks in which this age group has been previously shown to perform at above-chance levels.

Correlations with Frontal Lobe Development, Language, Temperament

Our understanding of IC task performance is greatly enhanced by examining the contributions to this performance. Three important contributors are those of frontal lobe development, language, and temperament.

Frontal Lobe Development. Frontal lobe development plays an important role in children's inhibitory abilities, so much so that researchers have argued that IC performance is the hallmark of frontal lobe function (Luria, 1973). Accordingly, research in those with frontal lobe deficits shows that those deficits relate to deficits in IC (Dennis, 1991; Diamond, Prevor, Callender, & Druin, 1997; Welsh, Pennington, Ozonoff, Rouse, & McCabe, 1990).

Indeed, development of the frontal lobes relates strongly to inhibitory task performance. Both human and rhesus monkey infants have difficulty with tasks of IC, such as the A-Not-B task, until their frontal lobe development begins to accelerate (Diamond, 1990a; Diamond & Doar, 1989; Diamond & Goldman-Rakic, 1989). Not all children develop at the same rate, of course, so it is also possible to observe, among typically-developing children, differences in frontal lobe maturation. Children who show less electroencephalographic (EEG) activity at frontal scalp locations during a baseline period also tend to do more poorly on tasks of IC (Wolfe & Bell, 2004), indicating that a lack of frontal lobe maturation impairs inhibitory abilities.

IC also differs among typically developing children and adults. One study taxed children and adults to play a classic go/no-go task while their frontal lobe response was measured via event-related functional magnetic resonance imaging. Although both children and adults showed more inhibitory errors as the number of "go" trials increased, only adults showed increased ventral prefrontal activation as a result of the increased interference. In contrast, children's prefrontal areas were maximally activated regardless of interference, suggesting that even during easier versions of the task, children's neural circuitry was drawn upon in its capacity (Durston et al., 2002). As such, it follows that young children, whose frontal lobes are still in the process of developing, will struggle with tasks of IC. Because of this, research has come to focus on electrical activity in the frontal lobes, an indicator of frontal lobe development, as it relates to children's inhibitory performance.

My dissertation study focuses on EEG as an indicator of frontal lobe development. In infancy, performance on the A-not-B IC task is related to EEG power values at frontal scalp locations (Bell & Fox, 1992; 1997), and infants with more developed IC showed baseline-to-task increases in activity, yet those with less developed IC did not (Bell, 2001). Similar research in 4.5-year-old children shows that children, regardless of verbal IC task performance, have higher medial frontal EEG during task than during baseline, and that children who performed better on these tasks had higher medial frontal activity than those who did poorly (Wolfe & Bell, 2004). One study in 3-year-olds explored the differences in contributions of frontal EEG to verbal and motoric IC, and found that EEG explained variability in task performance for a motoric task, but not verbal tasks (Watson & Bell, 2013). Because frontal EEG contributed to variations in verbal task performance in 4.5-year-old children, but not in 3-year-old children, this dissertation study is necessary to clarify the contributions of frontal EEG to IC throughout development, specifically in children at 4 years of age.

Language/ Intelligence. Language is also an important contributor to IC task performance. Children's receptive language, their comprehension of incoming language, is related to their IC task performance in early childhood (e.g., Carlson & Moses, 2001; Carlson et al., 2005; Wolfe & Bell, 2004; 2007), as is their expressive language, the language that they produce (Carlson, Mandell, & Williams, 2004).

It was previously argued that the contributions of language to IC task performance may be due to the language demands of the tasks themselves, and, in 3-year-old children, there is a difference in the contribution of language to verbal and motoric IC task performance (Watson & Bell, 2013). This relation, however, was unexpected in that language related to motoric IC task performance, which did not require children to speak, but not to verbal IC task performance, which did require children to speak. Again, this may be due to children's poor performance on tasks of verbal IC, or it may be due to the demands on receptive language required to understand task instructions.

The contributions of language to IC task performance, however, may also be due to the nature of childhood intelligence, which is highly related to language. In fact, one measure of receptive vocabulary, the Peabody Picture Vocabulary Test, correlates .88-.91 with the Wechsler Intelligence Scale for Children (WISC-III) Verbal Intelligence Quotient (IQ) scale as well as .89 with the Kauffman Adult Intelligence Test (KAIT) Crystallized IQ scale (Hodapp & Gerken, 1999; Pearson Assessments website, retrieved 7-2-12). Indeed, previous work emphasizes that intelligence cannot be fully understood without considering inhibitory process (Dempster, 1991). Therefore, my investigation considers the important contributions of language *and* intelligence on children's IC. The association with language is examined in order to remain consistent with prior research examining this association, and the association with intelligence is examined in order to determine the ways in which intelligence may influence IC in unique and overlapping ways from language.

Temperament. One final important contributor to IC task performance is temperament. IC can be measured not only as a laboratory task of executive function, but also as a temperament scale via the parental-report questionnaire, the Children's Behavior Questionnaire

(CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001). As may be expected, laboratory IC task performance relates to parental report of child temperament-based IC (e.g., Carlson & Moses, 2001; Kochanska, Murray, & Coy, 1997; Morasch & Bell, 2010; Wolfe & Bell, 2004). Both executive function-based and temperament-based IC also relate positively to academic and social outcomes in early childhood (Blair & Razza, 2007; Razza & Blair, 2009). However, cognitive and temperament-based IC also differ in that (1) they are often explored in different literatures, (2) laboratory-based measures of cognitive IC are typically collected in a controlled laboratory setting by experimenters who interact with all children, and (3) temperament-based IC is typically reported upon by mothers who see their children in a variety of uncontrolled settings but who may rate the same behaviors in different ways from one another. For this reason, it is important to understand the subtle differences that may arise in between cognitive and temperament-based IC, so this investigation examines the contribution of temperament-based IC to executive function-based IC.

Laboratory measurements of executive function-based IC also relate to other aspects of temperament. For example, they relate positively to CBQ attentional focusing and low intensity pleasure, and negatively to approach/anticipation (Wolfe & Bell, 2004; 2007). Because of these past associations, my investigation also considers the contributions of temperament to IC task performance.

Relations to Social and Academic Outcomes.

IC is also better understood in terms of its impact on child development. Two key areas of development to which IC contributes are the social and academic domains. Because IC contributes to both domains, it is important to examine the characteristics of IC in early childhood that help it to predict these important outcomes.

Social Outcomes. As described above, children's self-regulation protects them from disruptive social behaviors, including internalizing and externalizing problem behaviors, both concurrently and longitudinally, and when controlling for relevant social risk variables (Caspi et al., 1995; Eisenberg et al., 2009; Hughes et al., 2000; Kochanska & Knaack, 2003; Newman et al., 1997; Olson et al, 2005). Little is known, however, about the type of inhibition supporting this association.

It is difficult to find studies from which it would be possible to compare the correlates of verbal and motoric IC, because typically IC task performance is collapsed into composites according to older distinctions among tasks (e.g., Kochanska et al., 1997). However, performance on the Delay of Gratification task, a motoric IC task, relates positively to children's ability to get along with their peers and to manage friendships longitudinally (Mischel et al., 1988), and performance on Conner's Continuous Performance Task, a motoric IC task, predicts better social outcomes in adolescence, even when taking into account ADHD status (Rinsky & Hinshaw, 2011). To the best of my knowledge, there exist only two studies directly comparing the social correlates of verbal and motoric IC. One study found that response latencies on motoric, but not verbal, IC tasks related positively to externalizing behaviors in 4- and 6-year-old boys (Utendale et al., 2011). The other found that, in a sample of disadvantaged children, motoric IC was a more robust predictor of child social-emotional factors than was verbal IC (Rhoades et al., 2009). The authors of the second article argue that this pattern exists because motoric IC helps children to control aggression. Indeed, reactive aggression in childhood is related to social rejection (Price & Dodge, 1989). Therefore, children who are better able to control their bodily impulses, those with greater motoric IC, should be better able to function with their peers. This study examines this important finding in a sample of typically-developing children.

Furthermore, this study improves upon existing literature by exploring, alongside IC, the impact of intelligence on social outcomes. Low intelligence in children is associated with later delinquency (Farrington, 1987; Moffitt, 1993), yet age-appropriate language from the ages of 2 to 10 years protects children from delinquency (Werner, 1987). It stands to reason, then, that those children with lower intelligence in childhood may struggle more in their social interactions than those with higher intelligence. Because IC, too, plays an important role in social outcomes, it is likely that the two variables interact, such that those with low intelligence may rely more heavily on their inhibitory abilities than those with higher intelligence. In other words, those children with high intelligence may struggle less with social interaction and may be more easily forgiven for lapses in IC than do those with low intelligence. This investigation examines this hypothesis to determine if this interaction effect exists.

Academic/ School Readiness Outcomes. IC is also important to children's school functioning. Studies of IC and effortful control (EC) reveal that children who are regulated enjoy school more and have higher school competence, particularly in the domains of mathematics and reading achievement (Blair & Razza, 2007 ; Bull & Scerif, 2001; Bull et al., 2008; Espy et al., 2004; Fabes et al., 2003; Ponitz et al., 2009; Valiente et al., 2007; Welsh et al., 2010). Indeed a review of mathematics textbooks from the past 100 years found an emphasis on children's "thinking skills" and executive function abilities as they related to children's mathematical competence (Blair, Gamson, Thorne, & Baker, 2005). Verbally, IC, measured as an executive function, was the only aspect of self-regulation related to phonemic awareness in kindergarteners (Blair & Razza, 2007). Clearly, IC is of utmost importance to children's developing academic competence, but like with social development, little is known about the verbal versus motoric aspects of IC that help it to promote competence.

To the best of my knowledge, no study has compared the strength of relations between verbal and motoric IC and academic competence (in school-aged children) or school readiness (in preschool-aged children). However, several studies have examined these relations individually. Motoric IC tasks relate to early math and reading ability in preschoolers and kindergarteners, even when controlling for relevant variables such as age, gender, and maternal education (Blair & Razza, 2007; McClelland, Cameron, Connor, Farris, Jewkes, & Morrison, 2007; Espy et al., 2004). Verbally, performance on a Stroop task related to math in 7-year-old children (Bull & Scerif, 2001). In another study, performance on the motoric go/no-go IC task, as well as the Shape Stroop and Big/Little verbal IC tasks, at three years related to a mathematics performance task at 5 years and 3 months (Clark, Sheffield, Wiebe, & Espy, 2013).

It could be argued, however, that children's ability to control their bodies, more so than their ability to control their words, impacts their academic development. Indeed, teachers rate children as more prepared to begin school when they are better able to inhibit their behaviors (Denham, 2006). Children who are better able to control their bodies, children with superior motoric IC, possess the skills necessary to sit still in the classroom and to raise their hands before speaking. By sitting still, focusing on on-task behavior, they are theoretically better able to attend to the information presented to them. Therefore, although no study to date has examined the magnitude of the relations between both verbal and motoric IC and academic capabilities or school readiness, it is likely that a more robust correlation would be found for motoric IC.

My investigation, however, would be incomplete without also considering the impact of intelligence on children's school readiness. Although self-discipline predicts twice as much variance in school grades, school attendance, time spent doing homework, and other important academic variables than does intelligence (Duckworth & Seligman, 2005), intelligence does still certainly play a key role in children's academic outcomes. It follows then that intelligence and IC may interact to predict children's school readiness, such that those children who are more intelligent may not rely as heavily on their IC to help them to take in information in a learning environment.

For this reason, this study enhances existing literature by exploring the differing relations of verbal and motoric IC to social and school readiness outcomes, including the differing ways in which verbal and motoric IC interact with intelligence to affect these same outcomes.

Summary and Hypotheses.

In conclusion, IC, the ability to suppress a dominant response, as well as the ability to suppress irrelevant thoughts and behaviors, is a vital facet of childhood development. IC levels vary from child to child, even among typically-developing populations, making it suitable for studies of individual differences. Although IC emerges during the first year of life, its rapid development during the preschool years, coupled with children's tendency to perform at neither ceiling nor floor levels on tasks at this age, makes it especially relevant to study in 4-year-old children.

IC, though, can be measured by a wide-variety of tasks. Although much research has been devoted to studying the differences between certain classifications of tasks, for example, the differences between conflict IC and delay IC, or hot and cool IC, distinctions which often overlap, very few studies have explored the differences among the more unique distinction between verbal and motoric IC tasks. It is possible, though, that by exploring this distinction, we may discover important insight into the unique contributions to, and the outcomes of, children's abilities to control their words and their bodies, respectively.

The purpose of this study is to examine the differences among IC tasks that require children to give a verbal response from those that require them to give a motoric response. In the following analyses, I first examine differences between verbal and motoric IC tasks in terms of the contributions to IC of language, temperament, and frontal EEG activity. Next, I determine the unique ways in which verbal and motoric IC contribute to children's social abilities and their school readiness. Specifically, I use information gathered from the study to test the following hypotheses:

Difficulty of Tasks. Previous research on the subject was limited in that the 3-year-old subjects were not able to perform above chance levels on verbal IC tasks (Watson & Bell, 2013). I have chosen for this study tasks on which, in previous research, 4-year-old children have been able to excel, but on which there have been individual differences in performance rather than a ceiling effect. I hypothesize that the children in this study will also perform above chance level on all tasks, thus allowing for comparisons among tasks.

Relations to Electrophysiology. IC task performance is related to frontal EEG activity, such that children who perform well on IC tasks demonstrate higher overall EEG power values at frontal scalp locations, and show higher baseline-to-task increases in this activity than do than children who perform poorly on these tasks (i.e.: Wolfe & Bell, 2004, 2007). Although 3-year-old verbal IC was not described by frontal EEG (Watson & Bell, 2013), variance in motoric IC can be described by frontal EEG in 3- and 4.5-year-old children (Watson & Bell, 2013; Wolfe & Bell, 2004). To the best of my knowledge, data is not available that demonstrates the relations between EEG and verbal and motoric IC in 4-year-old children, however previous research predicts that EEG could predict verbal IC in children capable of above-chance performance on these tasks. For this reason, I hypothesize that frontal EEG will explain variance in both verbal and motoric IC in 4-year-old children, with children who perform well on these tasks showing higher EEG power values at frontal scalp locations as well as higher baseline-to-task increases in this activity than do children who perform poorly on these tasks.

Relations to Language and Intelligence. Performance on IC tasks has been traditionally found to relate to language (Carlson & Moses, 2001; Carlson et al., 2004; Carlson et al., 2005; Wolfe & Bell, 2004; 2007), perhaps because language serves as a proxy for intelligence. Intelligent children are likely better able to listen to and comprehend verbal task instructions, thus supporting strong performance on both verbal and motor IC tasks. For this reason, I hypothesize that both language and intelligence will relate positively to both verbal and motor IC task performance.

Relations to Temperament. As demonstrated in many other studies, laboratory measures of IC relate to maternal-reported IC (Carlson & Moses, 2001; Kochanska et al., 1997; Morasch & Bell, 2010; Wolfe & Bell, 2004). I hypothesize that task performance, regardless of verbal or motoric demands, in this study will also relate to maternal-reported IC. However, because research shows sporadic relations between laboratory IC task performance and other aspects of temperament (Wolfe & Bell, 2004; 2007), I explore the different patterns of relation between verbal and motoric IC task performance and other temperament scales and factors.

Contributions to Task Performance. Next, I examine contributions to performance on the individual verbal and motoric IC tasks. Based on previous research showing the importance of frontal EEG, language, and temperament, in that order (Watson & Bell, 2013; Wolfe & Bell, 2004; 2007) to task performance, I hypothesize that each will explain significant variance in IC task performance. Furthermore, because I hypothesize that this study will overcome challenges met in previous research (Watson & Bell, 2013), I hypothesize that each of these variables will contribute to task performance, regardless of the motoric or verbal nature of the IC task. Because verbal and motoric IC are unique from one another, however, I hypothesize that the relative impact of EEG, language, and temperament will vary between verbal and motoric IC. Because little is known about how verbal and motoric IC will differentially relate to each of these variables, analyses are exploratory in nature.

Social Outcomes. Next, based on previous research relating children's self-regulation to social outcomes, I predict that both verbal and motoric IC task performance will relate positively to measures of adaptive social functioning (e.g., Eisenberg et al., 2009; Hughes et al., 2000; Mischel et al., 1988). Furthermore, based on evidence that Luria's Peg Tapping Task, a task of motoric IC, was a more robust predictor of child social-emotional factors than was Day-Night, a verbal IC task, in disadvantaged 4- and 5-year-old children, as well as evidence that response latencies on the motoric Tapping Task, but not on the verbal Day-Night task, predicted externalizing behavior in 4- and 6-year-old boys (Rhoades et al., 2009, Utendale et al., 2011), I predict that tasks of motoric IC will relate more strongly to social outcomes than will tasks of verbal IC.

School Readiness Outcomes. Based on previous research relating children's self-regulation to school readiness and to academic indicators, I predict that both verbal and motoric IC task performance will relate positively to measures of school readiness (e.g., Blair & Razza, 2007; Bull & Scerif, 2001; McClelland et al., 2007; Espy et al., 2004). Furthermore, because of the importance of motoric IC to the ability to sit still in order to take in information, I predict that tasks of motoric IC will relate more strongly to school readiness outcomes than will tasks of verbal IC.

Moderating Effect of Intelligence. Finally, because an intelligent child may struggle less, both socially and academically, I hypothesize that intelligence may moderate the association between motoric IC and social and school readiness outcomes, such that motoric IC has the most beneficial effect on social and school readiness outcomes when intelligence is low. Because I hypothesize that the association between verbal IC and social and school readiness outcomes is weaker than that between motoric IC and social and school readiness outcomes, I do not hypothesize a similar interaction effect for verbal IC.

Importance of this Study. This study will contribute to the literature a more thorough understanding of the novel distinction between verbal and motoric IC in early childhood. To the best of my knowledge, only one study to date (Watson & Bell, 2013) has examined how children's performance on verbal and motoric IC tasks relate differently to the key variables of language, temperament, and electrophysiology. That study, however, was limited by 3-year-old children's poor performance on tasks of IC requiring them to speak. This study improves upon previous research by examining these relations in older children who should be capable of performing above chance levels on all tasks of interest. Furthermore, this represents the first study to examine the different ways in which verbal and motoric IC relate to social and school readiness outcomes in typically-developing children. By measuring relations among IC and these outcomes, this study will contribute to the understanding of the important role that verbal and motoric IC play in key aspects of childhood development. Therefore, by working with older children, by using a larger battery of tasks, and by measuring social and school readiness variables associated with IC, my dissertation study is better able to describe the similarities and differences among IC tasks which require a verbal response and those which require a motoric response.

Chapter 2

Method

Participants

Sixty-nine 4-year-old children (39 boys, 30 girls) contributed data to this investigation. At the time of the visit, children were 4 years of age (*M* = 4 years, 3.60 months, *SD* = 2.88 months, Range = 3 years 11 months – 4 years 11 months). I recruited children using the resources of the Virginia Tech Psychology Department's Developmental Science Database, which was compiled from commercial mailing lists as well as from parents who expressed interest in participating in research studies. I mailed recruitment invitation letters to parents of eligible participants, along with slips of paper which could be completed and returned in enclosed reply envelopes to indicate interest in the study. Furthermore, I posted, with permission, recruitment flyers in local daycares, preschools, and businesses. I also distributed, with permission, these flyers directly to parents at local preschools, daycares, and child-oriented events (i.e., Downtown Blacksburg Trick-or-Treating, Sinkland Farms Pumpkin Festival). I conducted subsequent phone conversations with those interested in participation. During this phone call, I further explained the specific details of the research design and scheduled a lab visit (See Appendix A for recruitment materials).

Of those who reported demographic information, all mothers and fathers had at least a high school diploma at the time of their child's birth. Ninety-four percent of the mothers had college degrees or higher, as did 83% of the fathers. At the time of the child's birth, mothers were approximately 31.4 years old (range 20-41) and fathers were approximately 32.9 years old (range 22-42). The majority of children were Caucasian (2 Hispanic, 3 Asian-American, 3 African-American, 3 multiple races). All children were full term and were healthy at the time of testing.

Parents were compensated with a $10 Target gift card for their participation. Furthermore, in response to recent work suggesting that self-control depletion over time may occur as a result of shifts in motivation and attention (Inzlicht & Schmeichel, 2012), all children earned stickers on a sticker chart for each task that they completed. This was done in order to keep motivation high throughout the experimental period. Accumulation of stickers was used to earn small toys, and all children left the laboratory with at least one small toy to thank them for their participation.

Design

Upon arrival at our research lab, participants and mothers were greeted by a research assistant who explained the study procedures and obtained signed consent from the mother (Appendix B) and verbal assent from the child (Appendix C). Mothers were seated beside and slightly behind their children throughout the visit.

All children spent approximately 1 to 2 hours in the laboratory, participating in a number of tasks designed to measure their IC, including the Day-Night, Yes-No, Silly Sounds, Grass-Snow, Hand Game, and Tapping Tasks. Electrophysiological data were collected through a 24-channel cap while children completed these tasks as well as during a baseline period during which children watched a short clip from a children's movie. Children completed the Peabody Picture Vocabulary Test as a measure of language, the Kaufman Brief Intelligence Test as a measure of intelligence, and the Woodcock Johnson as a measure of their school readiness while an experimenter fitted children with the EEG cap and prepared the cap for data collection. Prior to the appointment, mothers also completed the Children's Behavior Questionnaire regarding their child's temperament, the MacArthur Health and Behavior Questionnaire as a measure of their social functioning and school readiness, and a general information questionnaire as a measure of demographic data .

Measures

IC tasks. Children completed six tasks of IC, three tasks which required the child to give a verbal response (Day-Night, Yes-No, and Silly Sounds), and three which required the child to give a motoric response (Grass-Snow, Hand Game, and Tapping). Children were not given feedback during administration of the individual tasks. The order of task administration was counterbalanced so as to prevent effects from fatigue. All tasks were coded by two coders who were properly trained to establish high reliability.

Day-Night. The Day-Night Stroop-like task has been used in the developmental literature with children 3 ½ to 7 years of age and is hypothesized to involve the functioning of the dorsolateral prefrontal cortex (Diamond et al., 1997; Diamond & Taylor, 1998; Gerstadt et al., 1994). One set of laminated cards (10 cm×15 cm; Appendix D) was used. Each child was instructed to say “day” when shown a card with a picture of the moon and stars and to say “night” when shown a card with a picture of the sun, thus measuring the child’s ability to inhibit the urge to call each card by its intuitive name.

Each child was given two practice trials during which he or she is praised or corrected, followed by 16 test trials, eight with the sun card and eight with the moon card arranged in a pseudorandom order. The percentage of correct trials was calculated as the variable of interest. Total administration time was about 3 min. Previous research demonstrates that 4-year-old children perform with an average of 79% accuracy on this task (Diamond & Taylor, 1998). Interrater reliability was calculated for 68 of the 69 children and the resulting Intraclass Correlation Coefficient was .962.

Yes-No. The yes–no task (Kraybill & Bell, 2013; Wolfe & Bell, 2004, 2007), conceptually similar to the Day–Night task, requires children to inhibit and override their natural reaction to head nods and shakes. Children were instructed to say ‘‘no’’ when the experimenter nods her head and to say ‘‘yes’’ when the experimenter shakes her head, thus taxing children’s verbal IC. Children received 2 practice trials, during which they were praised or corrected, and 16 test trials, with 8 head nods and 8 head shakes arranged in a pseudorandom order. The percentage of correct trials was calculated as the variable of interest. Total administration time was about 3 min. When previously used with 4-year-old children in our lab, children performed with 61% accuracy (Wolfe & Bell, 2007). Interrater reliability was calculated for 68 of the 69 children and the resulting Intraclass Correlation Coefficient was .964.

Silly Sounds. The Silly Sounds Stroop (Willoughby et al., 2011), adapted from the Day-Night task (Gerstadt et al., 1994), requires children to say “woof” when presented with a picture of a cat, and to say “meow” when presented with a picture of a dog. Children were first asked to make the natural sounds of a dog, then cat. The experimenter then explained that in this game, children are to make dog sounds when shown a cat picture and to make cat sounds when shown a dog picture. One set of laminated cards (10 cm×15 cm; Appendix A) was used. Children received 2 practice trials, during which they were praised or corrected, and 16 test trials, with 8 dogs and 8 cats arranged in a pseudorandom order. The percentage of correct trials was calculated as the variable of interest. Total administration time was about 3 min. The task has been used in 4-year-old children (Ursache, Blair, Stifter, Voegtline, & Family Life Project Investigators, 2013), but researchers did not report mean performance on the task. However, children from 3.0 to 3.6 years of age were able to perform with 52% accuracy (Leemans, 2011).

Interrater reliability was calculated for 68 of the 69 children and the resulting Intraclass Correlation Coefficient was .982.

Grass-Snow. The Grass-Snow task (Carlson & Moses, 2001) requires children to place their hands on white and green cards placed on the table in front of them in a way that requires them to override their natural responses to the colors of grass and snow. Children were first asked to name the color of grass (green) and snow (white). The experimenter then instructed the child that in this "silly game", the child should touch the white card when the experimenter says "grass," and that they should touch the green card when the experimenter says "snow". Children received 2 practice trials, during which they were praised or corrected, and 16 test trials, with 8 "grass" and 8 "snow" arranged in a pseudorandom order. The percentage of correct trials was calculated as the variable of interest. Total administration time was about 3 min. Previous research demonstrates that 55% of 4-year-old children are able to pass this task with 75% accuracy (Carlson, 2005). Interrater reliability was calculated for 68 of the 69 children and the resulting Intraclass Correlation Coefficient was .997.

Hand Game. The Hand Game task used in this experiment is a variation of Luria's Hand Game task, which was originally used to measure IC deficits in adults with frontal lesions (Luria et al., 1964), and which was adapted for use with preschool-aged children by Hughes (1996, 1998, 1998b). Children were asked to place a flattened hand on the table whenever the researcher presented her fist and to present a fist whenever the researcher placed her flattened hand on the table.

Children were first asked to mimic the researcher as she made these shapes, so as to demonstrate that children have the ability to manipulate their hands into these shapes. Next, children were given the first rule of the game ("When I put my hand on the table, I want you to make a fist"). Instructions were repeated until children performed the correct action. Children were then given the second rule of the game ("When I make a fist, I want you to lay your hand flat on the table") and instructions were again repeated as necessary. Following instructions, each child was given at least one teaching trial for each condition. More teaching trials were given if they were necessary to demonstrate that the child understood the rules of the game.

The child was given at least two practice trials during which he or she was praised or corrected, and then 16 test trials were administered, eight with the experimenter's fist as the stimulus, and eight with the experimenter's flattened hand as a stimulus, arranged in a pseudorandom order. Total administration time was approximately 5 min. The percentage of correct trials was calculated as the variable of interest.

Although no previous research has specifically examined the performance of 4-year-old children on this task, research on children ranging in age from 3 years 3 months to 4 years 7 months demonstrates that children in this age group are capable of performing at above-chance levels with 52% accuracy (Hughes, 1998). Another study of 3-, 4-, and 5-year-old children shows that 58% of these children perform perfectly on this task, which an additional 24% made between one and two errors during a 5-trial administration (Lang & Perner, 2002). Thus, preschool children are able to perform above chance on the task, but the task is not subject to a ceiling effect. Interrater reliability was calculated for 68 of the 69 children and the resulting Intraclass Correlation Coefficient was .981.

Tapping Task. Luria's Tapping Task is another task originally devised to measure inhibitory deficits in patients with frontal lobe damage (Luria et al., 1964), but later altered to measure the inhibitory abilities of preschool- and early school-aged children (Diamond & Taylor, 1998). For this task, children were asked to tap a wooden dowel against a table twice whenever the experimenter first taps once, and to tap once whenever the experimenter taps twice. Children were instructed on these rules both verbally and through demonstration: “When I tap one time like this (Experimenter taps once), I want you to tap two times like this (Experimenter taps twice). Let’s try that. When I tap one time (Experimenter taps once), you tap,…” at which point the dowel was handed to the child. If the child responded incorrectly, the experimenter demonstrated the rule again, for as many trials necessary for the child to demonstrate understanding of the rule. If the child responded correctly, the experimenter praised the child and moved on to the second rule, which was taught (and the child’s correct performance praised) in the same manner.

The child was given at least two practice trials during which he or she was praised or corrected, and then 16 test trials were administered, eight with one tap as the stimulus, and eight with two taps as a stimulus, arranged in a pseudorandom order. Trials were conducted such that the experimenter tapped the dowel and then handed the dowel to the child for a response. The experimenter then took the dowel from the child, following the child’s response. This prevented the experimenter and child from tapping at the same time. Care was taken to ensure that the experimenter did not reach for the dowel too early or late, so that this reaching would not influence the child’s response. Total administration time was approximately 5 min. The percentage of correct trials was calculated as the variable of interest. Previous research demonstrates that 4-year-old children perform with an average of 81% accuracy on this task (Diamond & Taylor, 1998). Interrater reliability was calculated for 68 of the 69 children and the resulting Intraclass Correlation Coefficient was .994.

Peabody Picture Vocabulary Test. Receptive language was measured through the Peabody Picture Vocabulary Test (PPVT-IV, L.Dunn & D. Dunn, 2007), a nationally standardized instrument that measures receptive vocabulary and verbal comprehension. PPVT-III correlates .88-.91 with WISC-III Verbal IQ and .89 with KAIT Crystalized IQ (Hodapp & Gerken, 1999; Pearson Assessments website, retrieved 7-2-12). During laboratory administration, each child was shown arrays of four pictures and instructed to point to the picture that best describes a particular word. A standardized score was calculated based on the child's age and performance.

Kaufman Brief Intelligence Test. Children's intelligence was measured via the Kaufman Brief Intelligence Test (KBIT II, Kaufman & Kaufman, 2004). The KBIT includes measures of verbal and nonverbal intelligence, is appropriate for ages 4 through 90 years, and can be administered in approximately 20 minutes. A standardized score was calculated based on the child's verbal intelligence, nonverbal intelligence, and a combined intelligence.

Children's Behavior Questionnaire. The Children's Behavior Questionnaire (CBQ; Rothbart et al., 2001) was used to examine parent perceptions of child temperament. The CBQ is a 196-item questionnaire designed to measure general patterns of behavior in children of 3–7 years of age. It consists of 15 scales that load into 3 factors. Individual temperament scales have moderate to high internal consistency (Range; α = .64- .92) in 4- and 5-year-olds (Rothbart et al., 2001). Individual temperament scales in this sample also have moderate to high internal consistency (Range; α = .59- .80). The questionnaire was mailed to the mothers shortly after they scheduled their laboratory appointment, and was collected at the laboratory visit.

EEG. EEG data were collected while children completed the tasks of IC. Baseline EEG was measured as each child sat quietly for 2 min and watched a short, soothing, clip from the Disney film, *Finding Nemo* (turtles in the East Australian Current). Use of this procedure is intended to minimize eye movements and gross motor activity (Cuevas, Deater-Deckard, Watson, Kim-Spoon, Morasch, & Bell, in press; Watson & Bell, 2013). Mothers were seated in a chair beside the child and did not interact with the child throughout this recording.

Task administration began immediately after baseline recording. EEG recordings were made from 14 left and 14 right frontal scalp locations. EEG was recorded using a 24-lead stretch cap (Electro-Cap, Inc.) with electrodes in the 10/20 pattern (Jasper, 1958). Data of interest for this report will focus on the lateral frontal (F7/F8) location, because previous research has shown an association between IC task performance or executive function and lateral frontal EEG and/or brain matter (Bokura, Yamaguchi, & Kobayashi, 2001; Cuevas et al., 2012, Kraybill & Bell, 2013; Morasch & Bell, 2011; Watson, 2011, Zimmerman et al., 2006). Data were averaged across hemispheres, because my investigation does not include any hemisphere-specific hypotheses. After the cap was placed on the head, recommended procedures regarding EEG data collection with children were followed (Pivik, Broughton, Coppola, Davidson, Fox, & Nuwer, 1993). Specifically, a small amount of abrasive gel was placed into each recording site and the scalp gently rubbed. Next, conductive gel was placed in each site. Electrode impedances were measured and accepted if they were below 20 kΩ.

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

EEG data were examined and analyzed using EEG Analysis System software developed by James Long Company (Caroga Lake, NY). First, the data were re-referenced via software to an average reference configuration. The EEG data were then artifact scored for eye movements using a peak-to-peak criterion of 100 uV or greater. Artifact associated with gross motor movements over 200 uV peak-to-peak was also scored. These artifact-scored epochs were eliminated from all subsequent analyses.

The data were then analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-second width and 50% overlap. Across the children, the mean number of artifact-free DFT windows during baseline and tasks were analyzed, and child task data were included if the number of artifact-free DFT windows was equal to or exceeded 10. Power was computed for the 6 to 9 Hz frequency band. This particular frequency band is a dominant frequency in the early childhood year (Marshall, Bar-Haim, & Fox, 2002) and has been used previously with preschool children (Wolfe & Bell, 2004, 2007). For the current study, the power was expressed as mean square microvolts and the data were transformed using the natural log (ln) to normalize the distribution.

MacArthur Health and Behavior Questionnaire. The MacArthur Health and Behavior Questionnaire (HBQ) is a parent-report questionnaire of Likert-type scale questions addressing four components of children's healthy development: namely their mental health, physical health, social functioning, and school functioning. The questionnaire has been developed for use with children from 4 to 8 years of age (Essex et al., 2002). Of interest to this investigation are the Social Functioning scale, which is comprised of the following subscales of interest: (a) peer acceptance/rejection, (b) bullied by peers, (c) prosocial behavior, (d) overt hostility, (e) relational aggression, (f) asocial with peers, and (g) social inhibition and the School Functioning Scale, which is comprised of an (a) academic functioning scale and (b) an education services utilization scale. The education services utilization scale is under development and not of interest to this study. The academic functioning scale is optional for parents of preschool-aged children, but parents could elect to complete this scale. A total of 20 parents completed questions on this scale. Reliabilities for these scores ranged from $\alpha = .471$ to $\alpha = .871$.

Woodcock-Johnson. School readiness was assessed with the Woodcock-Johnson III (Woodcock, McGrew, & Werder, 2001). This test has been used in children and adults from 2 to 90 years old, and normative data on 8,800 subjects suggests good reliability and validity (Woodcock, Mcgrew, & Maher, 2001). Of interest to this investigation are one scale of emergent literacy, the Letter-Word Identification test, and one scale of emergent mathematical ability, the Applied Problems test. Task administration took approximately 10-15 minutes. Data previously collected on 4-year-old performance on these two tasks in our lab yielded good variability for the emergent literacy (mean = 8.25; SD = 3.76; min = 2; max = 15) and math (mean = 13.21; SD = 3.50; min = 5; max = 20) scales. Because the Woodcock Johnson Verbal Assessment test of Letter Word Identification was addressed in the proposal meeting for this dissertation as possibly relating too strongly to IC, I examined the relation between the two in a group of 56 four-year-olds who came through the lab as part of our longitudinal study. In that other sample, Letter Word Identification correlated with Yes-No task performance ($r = .342$, $p = .016$) but not with any other IC tasks (Pig-Bull, Day-Night, Hand Game, Gift Delay; all p's $\geq .234$). Megan McClelland and colleagues (McClelland et al., 2007) used the Letter Word Identification task as a measure of emergent literacy in 3- to 5-year-old children. In their assessment, they found that behavioral regulation correlated .25 with emergent literacy at one time point and .22 at another time point. For these reasons, I was able to continue collection with the Letter-Word Identification scale in addition to the Applied Problems scale.

Preschool Self-Regulation Assessment Assessor Report. The Preschool Self-Regulation Assessment Assessor Report (PSRA; Smith-Donald, Raver, Hayes, & Richardson, 2007) was used to code for children's off-task behavior, in response to concerns that children may not be able to remain on-task throughout the laboratory assessment. The PSRA Assessor Report was completed by two coders, one experimenter and one observer to the appointment. The variable of interest on the report regarded whether the child "sustains concentration; willing to try repetitive tasks". Interrater reliability was calculated for 100% of the sample and the resulting IntraClass Correlation Coefficient was .948. Average score on this variable was 2.20 (SD = .96, Range = 0-3; 0 = Child not able to concentrate or persist on much of the assessment, 1 = child frequently distracted, requires multiple prompts from assessor, 2 = child generally careful but interest flags, particularly at end of testing session, 3 = child takes time to look and appears to make thoughtful choices, particularly on hard items). Children's ability to sustain concentration related to their maternal reported IC ($r = .432$; $p < .001$), and their lab-measured verbal ($r = .360$; $p = .002$) and motoric ($r = .416$; $p < .001$) IC.

Chapter 3

Results

As described above, I calculated the percentage of correct trials for each IC task, standardized scores for the PPVT, scale and factor scores for the temperament measure, and scale scores for the social and school readiness measures (which did not have standardized scores). I analyzed EEG for each IC task as well as for a baseline period for comparison. Descriptive statistics for each of these variables of interest can be found in Table 2.

Data Reduction. Composite scores of latent constructs of correlated indicators provide more reliable measures of executive function than do individual task data (Carlson et al., 2004). Measures of IC in this investigation correlate with one another (see Table 3). As such, from this point, I test hypotheses regarding verbal versus motoric IC with analyses completed with respect to individual tasks as well as with respect to composites of variables. I created two composites, one for verbal IC tasks and one for motoric IC tasks, by first standardizing scores on the appropriate individual measures and then averaging these standardized scores into the aforementioned composites. Formation of composites in such a way is typical in IC research in early childhood (e.g. Carlson & Moses, 2001; Carlson & Wang, 2007; Kochanska, Murray, & Harlan., 2000). Composites are conceptual in nature, as is also typical in IC research in early childhood (e.g. Carlson & Moses, 2001; Carlson & Wang, 2007; Kochanska et al., 1996; Kochanska et al., 1997).

Principal Components Analysis. I then made an effort to support these conceptual composites with Principal Components Analysis (PCA). Using the example of Espy and colleagues (2004), I attempted to determine components by examining a scree plot and retaining factors with eigenvalues greater than 1 (Gorsuch, 1983). By doing so, I reached a one-component solution, in which the second eigenvalue was .959. Because this value was close to the traditional cut-off , and because it is acceptable to retain components which fall in the "elbow" of a scree plot (Cohen, Cohen, West, & Aiken, 2003), I examined the scree plot to determine if a two component solution would be a better fit for this model. I determined that the second component did, indeed, fall at this elbow (See Figure 1). As such, I forced a two-component solution, in which analyses were done with a promax rotation, which allows correlated components. Together, the two components explained 63.38% of variance in IC, and tasks loaded onto expected dimensions, with all motoric IC tasks loading onto one component and all verbal IC tasks loading on the other (Table 4). Correlations between individual IC tasks and composites can be seen in Table 3.

Difficulty of Tasks. In order to test the hypothesis that children would perform above chance levels on all IC tasks, I used one-sample t-tests to compare means on each individual task to the chance level value of 50%. This test, and all other tests labeled as such, was a one-tailed test, due to the directional hypotheses proposed above. This reduces the risk of inflated type-II error due to reduced statistical power that can be caused by using 2-tailed *p*-values when testing directional hypotheses (Hays, 1988, pp. 276-277). Because performance on all individual tasks exceeded chance value (all t's > 3.23, all p's < .01), no individual tasks needed to be dropped from Motoric IC or Verbal IC composites.

Relations to Electrophysiology. I tested the hypothesis that children who perform well on IC tasks will have higher lateral frontal (F7, F8) EEG power values at baseline and a larger increase in activation in this area from baseline and task by using multiple regression. The predicted variable in each regression was either verbal or motoric IC task performance. The first step of the equation was baseline frontal EEG activity, and the second was activity during task.

As can be seen in Table 5, frontal baseline EEG explains variance in Yes-No task performance. Task EEG explains variance in Yes-No above and beyond baseline EEG. Neither variable explains variance in any other verbal IC task or composite. As can be seen in Table 6, baseline and task EEG independently explain variance in Motoric IC task performance as a whole. Task EEG shows a trend toward predicting Hand Game performance. Neither variable explains significant variance in any other motoric IC task.

Relations to Language/Intelligence. In order to test the hypothesis that receptive language and intelligence would relate to both verbal and motoric IC, I calculated one-tailed, zero-order correlations between all tasks and the PPVT standardized language score, KBIT verbal intelligence score, KBIT nonverbal intelligence score, and KBIT intelligence composite. As can be seen in Table 7, all verbal and motoric IC tasks as well as their associated composites correlate with PPVT language, with the exception of Yes-No. All verbal and motoric IC tasks and composites also correlate with the intelligence composite. All verbal and motoric IC tasks correlate with verbal intelligence, with the exception of Yes-No, which is marginally associated. Finally, nonverbal intelligence related to motoric IC and to the verbal IC composite, but only marginally related to the individual verbal IC tasks.

Because differences arose in the magnitude of these correlations, I used a z-test of correlations to compare the strength of associations of each IC task and composite with language. As can be seen in Table 8, the strength of these associations did not differ by task or composite, however there was a trend toward Yes-No performance correlating less strongly with language than did Day-Night and Silly Sounds performance. Table 9 shows that Tapping Task performance relates more strongly to the intelligence composite than does performance on Yes-No and the Hand Game, with a marginal trend toward relating more strongly than does performance on Day-Night and Silly Sounds. It does not, however, relate more strongly than does Grass-Snow performance. Table 10 shows that neither verbal nor motoric IC relate more strongly than one another to verbal intelligence, but that there are differences in nonverbal intelligence. The motoric IC composite is more strongly associated than is the verbal IC composite. Tapping Task is more strongly associated with nonverbal intelligence than all verbal IC tasks as well as the Hand Game. Grass-Snow performance is more strongly associated with nonverbal intelligence than is performance on Silly Sounds and is marginally more associated than is performance on Day-Night, Yes-No, and Grass-Snow (all z's > 1.37, all p's < .09).

Relations to Temperament. I hypothesized that laboratory IC task performance would relate to maternal-reported IC. I tested with one-tailed, zero-order correlations between all tasks and the CBQ IC scale. As shown in Table 7, all IC tasks and composites related to maternal-reported IC, with the exception of Yes-No, which marginally relates. Table 11 shows that the magnitude of correlations between motoric and verbal task IC and maternal reported IC does not differ.

I also conducted exploratory analyses to determine if there is a pattern in any zero-order correlations found between IC task performance and any other CBQ scales or factors. As can be seen in Table 12, several associations exist. Activity level negatively correlates with all verbal and motoric IC tasks and composites, with the exception of Day-Night. Anger correlates negatively with only Day-Night. Approach positively correlates with Day-Night. Attention focusing does not relate to verbal IC but does positively correlate with Hand Game and the motoric IC task composite, and marginally relates with Grass-Snow and the Tapping Task. Discomfort does not correlate with verbal or motoric IC. Falling reactivity relates positively to Day-Night, negatively to Yes-No, and does not correlate with motoric IC nor with other verbal

IC. Fear positively correlates with Silly Sounds and the Verbal IC composite, and marginally relates with the verbal Yes-No task but only marginally correlates with one motoric IC task, the Hand Game. High intensity pleasure negatively correlates with Silly Sounds and the Verbal IC composite, and marginally relates to Day-Night. It also negatively relates to Grass-Snow, the Tapping Task, and the motoric IC composite. Impulsivity negatively relates to all motoric IC tasks, as well as to Day Night and the Verbal IC composite, and marginally negatively correlates with Yes-No and Silly Sounds. Low intensity pleasure does not relate to Verbal IC but does relate positively to the motoric Tapping Task and marginally relates to the Hand Game and the motoric IC composite. Neither perceptual sensitivity nor sadness relate to any IC tasks or composites. Shyness positively relates to Yes-No, Silly-Sounds, and the Verbal IC composite as well as to Grass-Snow and the Motoric IC composite, and it marginally relates to Hand Game and the Tapping Task. Smiling does not relate to any verbal or motoric IC tasks or composites, but it marginally negatively relates to Grass-Snow. The temperament factor, negative affect, also does not correlate with any verbal or motoric IC tasks or composites, but it does marginally correlate positively with Yes-No. Finally, the temperament factor of surgency negatively correlates with all verbal and motoric IC tasks and composites, with the exception of Day-Night, with which it marginally negatively correlates.

Contributions to Task Performance. Next, I examined contributions to performance on the individual verbal and motoric IC tasks, and their composites using multiple regression. Based on previous research (Watson & Bell, 2013; Wolfe & Bell, 2004), for both types of tasks, I expected EEG to have the strongest contribution to this prediction, followed by temperament and language, so variables were entered into the regression in this order. As can be seen in Table 13, the combination of all variables explained variance in only Silly Sounds performance.

Regarding the contribution of individual variables, PPVT explained variance in Silly Sound performance, and marginally explained variance in Day-Night performance when controlling for EEG and temperament. Table 14 shows that the combination of all variables explained variance in Grass-Snow performance as well as in the Motric IC composite. Regarding individual task contributions, lateral frontal baseline EEG, lateral frontal task EEG, and temperament each contributed unique variance to Motoric IC composite scores. Temperament and language both marginally contributed to variance in Grass-Snow performance.

Because I hypothesized that verbal and motoric IC are unique from one another, but there is no prior research to support how this will affect the strength of relations between EEG, language, and temperament and task performance, I used exploratory analyses to examine these associations. Namely, I computed regression equations in which these predictor variables are now my predicted variables, and verbal IC, motoric IC, and the interaction between the two are now the predictor variables. As can be seen in Table 15, the combination of verbal and motoric IC and their interaction predicts significant variance in temperament and language. Verbal IC predicts variance in language above and beyond the contribution of Motoric IC. Motoric IC marginally uniquely predicts temperament.

Contributions to Social Functioning. In order to test the hypothesis that social functioning would relate positively to both verbal and motoric IC, I calculated one-tailed correlations between verbal and motoric IC and the social functioning scales. As can be seen in Table 16, peer acceptance correlated only with Grass-Snow, positively. Whether or not the child was bullied related only to Day-Night performance, negatively. Prosocial behavior did not relate to any IC scales or tasks, but marginally positively related to Tapping Task performance. Overt hostility was negatively correlated with Grass-Snow performance and marginally correlated with

Day-Night performance. Relational aggression negatively correlated with Day-Night and the Verbal IC composite as well as Grass-Snow and the Motoric IC composite. It was also negatively marginally correlated with Hand Game performance. Social behavior positively correlated with Silly Sounds, Hand Game, Tapping Task, and the Motoric IC composite. It positively marginally correlated with Yes-No, the Verbal IC composite, and Grass-Snow performance. Finally, social inhibition correlated with all IC tasks and composites.

Because intelligence is related to social outcomes, I then conducted an analogous set of partial correlations, controlling for intelligence (Table 16, values in italics). After doing this, peer acceptance continued to correlate only with Grass-Snow performance. Whether the child was bullied, their prosocial behavior, and their overt hostility no longer correlated with IC. Relational aggression negatively correlated with Day-Night and Silly Sounds task performance and the Verbal IC composite, as well as Grass-Snow performance and the Motoric IC composite. It also negatively marginally correlated with Hand Game performance. Asocial behavior was positively correlated only with the motoric Hand Game, Tapping Task, and Motoric IC composite. Finally, social inhibition continued to positively correlate with all IC scales and composites, with the exception of the verbal Yes-No task, with which was marginally correlated.

In order to test the hypothesis that social functioning relates more robustly to motoric, rather than verbal, IC, I used a z-test of correlations to compare the strength of the above-described partial correlations. I conducted these z-tests on scales on which there were significant correlations, meaning that I did not conduct these analyses on the bullied, prosocial, or overt hostility scales. The association between peer acceptance and Grass-Snow performance was stronger than that between peer acceptance and Hand Game (z= 1.86, p= .03) but not any other tasks (all z's < 1.28, all p's > .10). As can be seen in Table 17 (lower triangle) and Table 18, verbal and motoric IC tasks and composites did not differ from one another in the strength of their association with relational aggression or social inhibition. However, Hand Game performance was significantly more strongly associated with the asocial scale than was Day-Night, Silly Sounds, and Grass-Snow performance. It was also marginally more related than was Yes-No performance. The motoric IC Tapping Task was also more strongly related than the Verbal IC Day-Night, and the Motoric IC composite was marginally more strongly associated with the asocial scale than was the Verbal IC composite.

Contributions to School Readiness. In order to test the hypothesis that school functioning would relate positively to both verbal and motoric IC, I calculated one-tailed correlations between verbal and motoric IC and the social functioning scales. As can be seen in Table 16, academic competence positively related to all IC tasks and composites, with the exception of Grass-Snow, to which it marginally related. Emergent Literacy positively correlated with all Motoric IC tasks and composites, and it marginally related to Day-Night. Math performance positively related to all verbal and motoric IC tasks and composites.

Because intelligence is related to social outcomes, I then conducted an analogous set of partial correlations, controlling for intelligence (Table 16, values in italics). After doing this, academic competence continued to relate to the Verbal IC Yes-No and Silly Sounds tasks, as well as the Verbal IC task composite. It also positively correlated with the Motoric IC task composite and marginally positively correlated with the Hand Game and Tapping Task. Emergent Literacy continued to positively correlate with the motoric Tapping Task and marginally correlated with Day-Night, the Hand Game, and the Motoric IC task composite. Finally, math performance continued to be positively correlated with the Verbal IC task composite as well as the Yes-No and Silly Sounds tasks. Math performance also positively correlated with Grass-Snow, Tapping Task, and the Motoric IC composite, and marginally positively correlated with Hand Game performance.

In order to test the hypothesis that school readiness relates more robustly to motoric, rather than verbal, IC, I used a z-test of correlations to compare the strength of the above-described partial correlations. As can be seen in Table 19 (lower triangle) and Table 20, verbal and motoric IC tasks and composites did not differ from one another in the strength of their association with parent-reported academic competence or lab-based math performance. However, as seen in Table 19 (upper triangle) the correlation of Day-Night and emerging literacy was significantly more negative than was the positive correlation of the verbal Yes-No task and the motoric Hand Game and Tapping Task. Furthermore, the association between the verbal Silly Sounds task and emerging literacy was marginally more negative than was the positive correlation of the motoric Hand Game and Tapping Task with emerging literacy. Finally, the negative association between the Verbal IC composite and emerging literacy was marginally more negative than the positive association between the motoric IC composite and emerging literacy.

Moderation Model. In order to test the hypothesis that intelligence would moderate the relation between motoric IC and social and school readiness outcomes, I conducted two separate regression analyses, one with social outcomes as the dependent variable, and one with school readiness outcomes as the dependent variable. Variables were entered into the equation in the following order: motoric IC in the first step, KBIT Standard Composite in the second step, and an interaction term in the third step. The interaction term was computed by multiplying standardized values for the KBIT and motoric IC. Because these analyses revealed unexpected findings, I then conducted an analogous set of post-hoc analyses, with social or school readiness outcomes as the dependent variable and verbal IC in the first step, KBIT in the second step, and an interaction term (of verbal IC and KBIT) in the third step of the equation. As can be seen in Tables 21-24, the interaction term did not describe unique variance in the school readiness variables for verbal or motoric IC. However, in the motoric IC analyses, the interaction term predicted variance in social inhibition, and in the verbal IC analyses, the interaction predicted variance in prosocial behavior. Probing the interactions reveals that motoric IC most strongly relates to social inhibition when intelligence is high (Figure 2) and that verbal IC relates positively to prosocial behavior when intelligence is high but relates negatively to prosocial behavior when intelligence is average or low (Figure 3).

Effects of Gender. Not reported here are post-hoc analyses regarding the effects of gender on each of these analyses. Girls' performance exceeded that of boys on key variables such as emerging literacy, intelligence, and motoric, but not verbal IC. As such, the associations reported above sometimes varied by gender. Future work will explore the effects of gender on the differentiation between motoric and verbal IC.

Chapter 4

Discussion

Children's IC, their ability to suppress a dominant response, as well as the ability to suppress irrelevant thoughts and behaviors, has important social and academic consequences. Because of this, there exist a number of measures of IC appropriate for use in early childhood. Due to the task impurity problem, researchers have developed a number of dichotomies based on distinctions among these tasks. However, these dichotomies, though differing in their theoretical roots, show a considerable amount of overlap in the tasks chosen to measure them. For this reason, I chose to examine a unique, non-overlapping, distinction based on whether tasks require children to control their words or their physical movements. Therefore, this investigation enhances the IC literature by revealing the similarities and differences between verbal and motoric IC as they relate to various developmental correlates. Namely, it explores differences with respect to the contributions to verbal and motoric IC performance of language, intelligence, temperament, and frontal encephalography, as well as with respect to social and school readiness outcomes. This research provides evidence of a distinction between verbal and motoric IC, and it underscores the utility of including in early childhood investigations a large battery of IC tasks.

The distinction between verbal and motoric IC has been examined once before, in 3-year-old children (Watson & Bell, 2013). That study found that frontal EEG, language, and temperament predicted performance on the motoric IC task, the Hand Game, but not on the verbal IC task, Day-Night. However, it is difficult to draw strong conclusions from this previous research, because children performed at chance level on the verbal IC task. Because of this, the current investigation focused on older children who could be expected to perform at higher levels on the tasks, such that they would not be subject to such floor effects. Indeed, 4-year-old children's average performance in the current investigation exceeded chance levels, as expected, thus allowing for stronger conclusions to be drawn about the fundamental differences in contributions to children's performance on verbal and motoric IC tasks.

Data Reduction and Task Performance

Formation of Composites. Because performance on IC tasks exceeded chance levels, and because verbal and motoric IC tasks correlated among one another, I created two composites, one Verbal IC Composite and one Motoric IC Composite. Composite scores of latent constructs of correlated indicators provide more reliable measures of executive function than do individual task data (Carlson et al., 2004). Traditionally, early childhood IC researchers form such composites conceptually, based on theoretical associations among tasks (e.g. Carlson & Moses, 2001; Carlson & Wang, 2007; Kochanska et al., 1996; Kochanska et al., 1997). However, the results of this investigation indicate that a distinction between verbal and motoric IC can also be made statistically, with a PCA revealing a two-component solution as acceptable. This is unique. Traditionally, early executive function is best statistically described by one-factor models before 6 years of age (Hughes, Ensor, Wilson, & Graham, 2010; Wiebe et al, 2008; Wiebe et al., 2011). It is likely that the breadth of the investigative batteries is the reason for the one-factor models. Hughes and colleagues used only 3 tasks in their study, one of IC, one of working memory, and one of planning. Wiebe and colleagues had a larger batteries, but the 2008 investigation only included two measures of verbal IC (Shape School and Whisper Task) and the 2010 investigation only included one (Shape School). Perhaps by including three tasks of each verbal and motoric IC, the current study was better able to capture a range of variability that allowed for the two-composite solution to be found.

Task Performance as Compared to Previous Research. Children performed at roughly average levels compared to their peers from previous studies. Performance on Day-Night (60%) was slightly lower than previous studies (79%; Diamond & Taylor, 1998). Yes-No performance (72%) was slightly higher than average (61%, Wolfe & Bell, 2007). Silly Sounds performance (63%) was, not surprisingly, higher than that of previously-studied 3-year-old children, the closest age-range in which data has been reported (52%, Leemans, 2011). Among the Motoric IC tasks, 55% of previously studied 4-year-olds were able to pass Grass-Snow with 75% accuracy (Carlson, 2005), and children in the current study were able to perform with 75% accuracy. Children in the current study performed with 86% accuracy on the Hand Game, whereas 58% of previously studied 3-, 4-, and 5-year olds performed perfectly (Lang & Perner, 2002). Finally, 4-year-old children in the current investigation performed with 68% accuracy on the Tapping task, whereas previously-studied 4-year-old children performed with 81% accuracy (Diamond & Taylor, 1998).

Among the non-IC-task variables, the children in this sample were also mostly average. Parental report of their IC was 4.67 on a 7-point scale. This is in line with the finding that 4- and 5-year-old children average a score of 4.75 on the IC scale (Rothbart et al., 2001). Children's intelligence was also average, with average child performance near 100 on the KBIT verbal and nonverbal scales as well as the composite. Interestingly, despite the similarities reported between verbal intelligence and language (Hodapp & Gerken, 1999; Pearson Assessments website, retrieved 7-2-12), child language scores in this sample were higher than average. It is likely that this has to do with the order in which tasks were presented. Although all IC tasks were counterbalanced, the PPVT, Woodcock Johnson, and KBIT were presented in a set order. It is possible that children's scores on each of these were reflective not only of their intellectual capabilities but also their endurance. Indeed, self-control and vigilance are limited capabilities that can become depleted over time (Muraven & Baumeister, 2000). Therefore, it is likely that children gave more careful answers during PPVT administration than they did during KBIT administration, thus reflecting the difference in scores.

Contributions to IC

Relations to Electrophysiology. This investigation also yielded surprising results regarding the association between frontal EEG and IC task performance. Although previous research has traditionally focused on the associations between medial frontal electrophysiology and IC (e.g., Watson & Bell, 2013; Wolfe & Bell, 2004, Wolfe & Bell, 2007), this investigation revealed no association between IC and scalp electrical activity at the medial frontal or frontal pole areas, nor was there an association between IC and EEG activity averaged across all frontal electrodes (pole, medial, lateral). Lateral frontal activity, however, did relate to IC task performance in this investigation. Previous research has also shown an association between IC and lateral frontal EEG activity (e.g. Kraybill & Bell, 2013; Morasch & Bell, 2011, Watson, 2011). Baseline and task EEG both contributed to Yes-No verbal IC task performance as well as to the motoric IC composite. Baseline EEG contributed positively to both. Stronger baseline activity is typically considered to be an indication of frontal lobe maturation (Cuevas et al., 2012), meaning that these findings indicate an association between frontal maturation and better IC task performance. Interestingly, when controlling for baseline activity, task activity during the verbal Yes-No task and during a combination of all motoric IC tasks made a negative contribution to IC task performance. The anterior cingulate cortex plays a role in cognition and attention (Bush, Luu, & Posner, 2000), so perhaps children who performed well on the IC tasks, those children with higher frontal baseline EEG, needed to allocate less attention to the task at hand than did children who performed less well on the task, because they already possessed the cognitive capabilities to demonstrate strong IC.

The study differs from the Watson and Bell (2013) study in that I found an association between verbal IC and frontal EEG. The Yes-No task relates to concurrent baseline to task changes in medial frontal EEG in 4.5-year-old children (Wolfe & Bell, 2004). These same baseline to task changes in medial frontal EEG also relate to a composite of Day-Night and Yes-No task performance in 4- and 4.5-year-old children (Wolfe & Bell, 2007). Baseline frontal EEG at 10 months also relates to an executive function composite, which includes Yes-No, at 4 years. This suggests that, as hypothesized, the lack of association between EEG and verbal IC previously found in 3-year-old children (Watson & Bell, 2013) could be due to children's poor performance on the task, and that this investigation is able to elucidate the association by including as participants older children who were capable of performing above chance levels on verbal IC tasks. Furthermore, the current investigation supports previous research by also finding an association between EEG and motoric IC. Interestingly, this association was only found at the composite level, suggesting once again that it is preferable to analyze composite data rather than individual task data (Carlson et al., 2004). It is likely that this investigation would have also found an association between the verbal IC composite and frontal EEG had more children provided electrophysiological data. However, 8 children refused to wear the EEG cap and 1 other moved excessively during task administration. This amounts to a 13% loss of EEG data. In a similar investigation of 4-year-old children, researchers lost 14% of electrophysiological data for the same reasons (Cuevas, Hubble, & Bell, 2012), and 12% of 4.5-year-old electrophysiological data was lost to cap refusal in another study (Wolfe & Bell, 2004).

Therefore, children in this study contributed EEG data at the same rate as those in comparable studies. However, because we lost some EEG data, the degrees of freedom remaining in the analyses may have been too small to see the predicted effects.

Relations to Language and Intelligence. All IC tasks, with the exception of the verbal Yes-No task related to language, and verbal IC did not relate more strongly to language than did motoric IC. Similarly, all IC tasks, with the exception of Yes-No, also related to verbal intelligence, again with no differences in the strength of associations between verbal intelligence and verbal IC and verbal intelligence and motoric IC. This is consistent with the finding that children's verbal intelligence and language overlap considerably (Hodapp & Gerken, 1999; Pearson Assessments website, retrieved 7-2-12). There are a number of similarities between the PPVT and the verbal scales of the KBIT. Although not identical, both contain components in which children must respond to a spoken word by pointing to the picture of that word on a page which displays multiple pictures. Some of the same words, including "furry", are included in both tests. The fact that verbal and motoric IC related equally well to both also suggests that the association between language and IC is unrelated to the speaking demands of the tasks themselves. The lack of association between Yes-No performance and both language and intelligence was unexpected, given that all other verbal IC tasks, and the composite, related to both, but given the marginal associations found, it is likely that an association would be found in a larger sample.

All IC tasks related to the full intelligence composite, with the motoric Tapping Task relating more strongly than the individual verbal IC tasks. When probed, it appears that this difference in associations is driven by the nonverbal intelligence scale. Motoric IC is either marginally or fully more strongly associated with nonverbal intelligence, at the individual task and composite levels, than is verbal IC. It is tempting to draw the conclusion that this results from similarities between the motoric IC tasks and the nonverbal intelligence measures. Although both required children to provide nonverbal responses, the nonverbal intelligence scale required children to answer series of analogies by pointing to pictures within an array, whereas the motoric IC tasks required children to withhold a dominant physical response in interaction with the experimenter. Yet, despite the dissimilarities in task administration, the association persists. A similar association was found between 3- to 5-year-old children's performance on the motoric Peg Tapping Task and their kindergarten performance on the fluid nonverbal intelligence test, Raven's Colored Progressive Matrices Test, which, like the nonverbal scale of the KBIT, required children to complete patterns(Blair & Razza, 2007). The authors chose to measure both fluid nonverbal intelligence and IC in this sample of children, due to differences between fluid cognition and general intelligence, namely that fluid cognition may be more strongly influenced by early emotional development (Blair, 2006). It is possible, then, that verbal IC is more strongly impacted by early emotional experiences than is motoric IC, allowing motoric IC to maintain a stronger association with nonverbal intelligence.

Relations to Temperament. Performance on all IC tasks related positively to parental report of IC, with the exception of the verbal Yes-No task, which marginally related. There were no differences in the strength of associations found between temperament and verbal and motoric laboratory IC measures. Other studies have also shown an association between maternal-report IC and laboratory IC (e.g., Carlson & Moses, 2001; Kochanska et al., 1997; Morasch & Bell, 2010; Wolfe & Bell, 2004). The reoccurrence of this association is reassuring in that it implies that the IC that parents are able to observe in natural situations is similar to the IC observed in our less-natural but more highly-controlled laboratory IC measures. The current investigation adds to our current understanding of IC by showing that maternal report does not relate differentially to our laboratory understanding of verbal or motoric IC, implying that parents observe both in their daily interactions with their children.

What's more, the current investigation revealed a number of sporadic associations with other maternal-reported temperament scales and factors. As previously found in this age group, laboratory IC positively related to attention focusing (Wolfe & Bell, 2004; 2007). Interestingly, the attention focusing scale related to motoric IC, but not verbal IC. This is consistent with the finding that attention focusing related only to the motoric Simon Says task and not the verbal Yes-No or Day-Night tasks (Wolfe & Bell, 2007). The investigation also found evidence that those children with higher activity levels, impulsivity, and surgency, not surprisingly, had lower levels of IC. High intensity pleasure, too, was generally negatively associated with verbal and motoric IC, suggesting that children who show extreme happiness may have difficulty regulating their behavior. A few unexpected findings emerged as well. For example, children's fear positively related to the verbal IC composite, and their falling reactivity/soothability positively related to one verbal IC task but negatively related to another, and neither fear nor falling reactivity related to motoric IC. These differential associations suggest differences between verbal and motoric IC that should be explored in more depth in future studies.

Most interestingly, shyness positively related to the verbal and motoric IC composites as well as to many individual tasks. This was unexpected, as previous research has shown a negative correlation between 4-year-old shyness and concurrent IC (Wolfe, Zhang, Kim-Spoon, & Bell, 2014). The positive association in my study could be related to the trait of behavioral inhibition, a temperament involving fear in the presence of novelty. Behavioral inhibition, which is associated with anxiety problems in adolescence and adulthood (Chronis-Tuscano et al., 2009), leaves children at increased risk for social reticence (Fox, Henderson, Marshall, Nichols, & Ghera, 2005). Among children with high levels of behavioral inhibition, high levels of IC increase the risk of anxiety at 4 and 5 years of age (White, McDermott, Degnan, Henderson, & Fox, 2011). It is possible, then, that the association that we see between shyness and IC is reflective of the children in our sample with characteristics of behavioral inhibition. Interestingly, the association between behavioral inhibition and social withdrawal is weakened among children with no bias toward threat and absent among children who avoided threat (White et al., 2011). Therefore, future research into the association between shyness and inhibitory control should include measures of behavioral inhibition, threat bias, and threat avoidance in order to better clarify contributions to this unexpected association.

It is important at this point to acknowledge the large number of z-tests that were conducted in order to determine if verbal or motoric IC related more strongly than one another to language, intelligence, and temperament. The purpose of these tests was to tease apart statistically significant differences from correlations that only appeared to be stronger than others. However, it should be acknowledged that the differences among correlations necessary to produce a statistically significant result varies as a result of sample size, meaning that a smaller sample with the same associations would produce fewer statistically significant z-tests, whereas a larger sample would have produced more. For this reason, it is important not to over-interpret the differences between traditionally significant z-test results and those which were only marginally significant, and it is more important to examine the data for trends in these results. From these trends, it is clear that motoric and verbal IC differentially related to intelligence, driven by nonverbal intelligence, whereas they are very similar in their associations with language and temperament.

It is also worth noting at this point the way in which Yes-No task performance often does not relate in the same ways to common IC correlates as do the other IC tasks. Yes-No is a relatively new task, introduced into the IC literature within the previous decade (Wolfe & Bell, 2004). Therefore, there is not yet a great deal of research to elucidate its associations with common correlates. However, previous research shows that a composite including the Yes-No task relates to frontal EEG and to temperament (Wolfe & Bell, 2004; Wolfe & Bell, 2007) as well as to language (Wolfe & Bell, 2007). This investigation showed only marginal associations between Yes-No and temperament, and EEG, and no association with language. It is possible that some variability was lost due to a ceiling effect in the data, because children scored higher on the Yes-No task than any other verbal IC task. Yet, average motoric IC tasks scores were often higher than Yes-No task performance. Interestingly, Yes-No was also the only verbal IC task with a truncated range of performance. All children answered correctly on at least one trial of this task, which was not true for the Day-Night or Silly-Sounds tasks. Again, this truncated range alone is not enough to describe the interesting pattern of results found, because two motoric IC tasks also showed a truncated range of correct responses. It is possible then that the effects of decreased variability on verbal IC tasks differ from the effects on motoric IC tasks. More research using the Yes-No task is needed to determine if this unexpected pattern of associations is unique to this sample or if other studies in this age range will show similar effects.

Contributions to IC. After investigating the individual contributions that EEG, language, and temperament made to IC, I then examined the ways in which a combination of each of these variables contributed to IC. Among the verbal IC tasks, a combination of the variables described only Silly Sounds performance. Among the motoric IC tasks, a combination of the variables described Grass-Snow performance as well as the motoric IC composite.

However, a combination of the variables was not able to describe performance on any other individual task or composite. It appears then that a great deal of the variability that each of these variables contributes to IC is shared variance. What's more, this lack of association may also reflect lower power values for analyses including EEG. A number of children either refused to wear the EEG cap or they had trouble sitting still, introducing too much motor artifact into their data. As a result, the number of data points included in the EEG analyses is far exceeded by the other variables, on which many had full or nearly full data. Thus, including EEG in an analysis reduces power values and may hide other effects.

Another important piece of information garnered from these analyses is that of the individual variability that each variable was able to contribute to the IC tasks when controlling for the other variables of interest. In most cases, the individual *p*-values exceeded .05, suggesting that EEG, language, and temperament are no more or less important than one another in predicting IC task performance. What's more, it should be noted that we do not see tremendous differences between verbal and motoric IC tasks in this respect, suggesting that each of these variables is important to both varieties of IC. This finding underscores the importance of including a number of variables of interest in future studies in order to capture a wide range of variability that may differ among verbal and motoric IC tasks.

Next, the regressions were conducted in reverse in order to determine the ways in which verbal and motoric IC individually contributed to language, temperament, and EEG, as well as the contribution that their interaction had on these variables. Importantly, their interaction did not contribute significant variance in each of these equations. However, motoric IC marginally uniquely predicted temperament-based IC, and verbal IC uniquely predicted language. Perhaps, in this instance, parents are better able to observe motoric IC in their children, such that their reports of their children's IC more accurately reflect motoric, rather than verbal, IC aspects. The verbal IC and language association is less clear, given that language was not more strongly associated with verbal than motoric IC, yet it still remains that, when controlling for motoric IC, verbal IC is still significantly related to language. It could be that verbal IC, that ability to control one's words, could positively impact children's listening skills, allowing them to learn new words, however future research is necessary to elucidate this association.

Contributions to Social and School Readiness Outcomes

IC also has important consequences for children's social and academic development. As such, it is important to determine the unique and overlapping ways in which verbal and motoric IC relate to these outcomes in early childhood, because findings from this work have the potential to influence future early intervention techniques.

Contributions to Social Functioning. As expected, both verbal and motoric IC were associated with the negative social characteristic of relational aggression. However, unexpectedly, asocial behavior was positively associated with motoric IC, but not verbal IC, and social inhibition was positively associated with both, even when controlling for intelligence. It appears that this may be related to the finding above that shyness, too, related to IC. Perhaps my sample included a subset of behaviorally inhibited children whose high IC contributed to social difficulties (White et al., 2011). This, however, does not explain why children's asocial behavior was more strongly associated with motoric rather than verbal behavior. This answer more likely lies in the questions used to probe at asocial behavior. Parents reporting asocial behavior in their children did so by indicating agreement with statements such as that their child "prefers to play alone", "avoids peers," "withdraws from peer activities" and other similar statements, all referring to children's physical withdrawal from peers. Given the association between IC and social reticence in behaviorally inhibited children, it may be reasonable to theorize that those who excel in motoric IC are more likely to physically withdraw from peers, yet those excelling in verbal IC may be more likely to simply withdraw from conversation, thus explaining the differential relations between verbal and motoric IC and parental report of this largely motoric asocial behavior. Lending support to this hypothesis is the finding that "social inhibition", reported on using items such as "shy with other children" and "shy with unfamiliar adults", which could be observed in both verbal and physical domains, relates equally well to verbal and motoric IC.

The association between social inhibition and motoric IC was also impacted by a moderating role of intelligence, such that the association between motoric IC and social inhibition was the strongest in highly intelligent children. Previous research suggests that children struggling with behavioral inhibition may be better able to overcome their anxieties when they are intelligent (Asendorpf, 1994), so this is not merely the conglomeration of two traits independently and together leading to a negative social consequence. Rather, it is likely that the answer lies in the giftedness of the child. Classic research and theory suggest that children who are gifted may withdraw socially, because they find that they do not fit in with their less gifted peers (see Roedell, 1984 for review). Indeed, in this sample, one mother wrote as marginalia to one questionnaire, "I believe most sensitivities and not fitting in with peers relates to giftedness". The interaction found in this study supports this classic research as well as this mother's suspicions by suggesting that possessing a combination of high motoric IC and high intelligence may cause a child to withdraw from social situations.

My investigation also revealed an interaction between verbal IC and intelligence, in their relation to prosocial behavior. In this interaction, there was a positive association between prosocial behavior and verbal IC in highly intelligent children, but no, or perhaps a negative, association between the two in less-intelligent children. Again, this finding may be explained by the statements used to assess child behavior. Parents reported on child social behavior by rating agreement with statements such as “if there is a quarrel or dispute (s)he will try to stop it” and “shows sympathy to someone who has made a mistake”. Both of these statements, and many other on the scale, describe complex situations in which children must recognize a problem as well as consider and enact a solution. Although an intelligent child, high in IC, may be able to do just this, recognizing a problem, thinking of a solution, and using their verbal IC to withhold inappropriate responses (i.e., “you dropped that toy!”) while also offering a solution (i.e., “here; have my toy!”), a less intelligent child, still high in verbal IC, lacking a solution, and possibly lacking the understanding of a need to inhibit a verbal response, may seem less prosocial in such a situation.

Alternatively, the interaction between verbal IC and intelligence in their relation to prosocial behavior could be explained by the differences between prosocial activiation and prosocial inhibition. All questions on the prosocial behavior scale were indicative of prosocial activiation, meaning that they asked parents to report on times when children were acting in a prosocial manner by putting forth effort in joining or maintaining a positive social situation. However, children could also have a positive social influence by withdrawing from a negative social situation. Therefore the negative association between inhibitory control and prosocial behavior in children of lower intelligence could be indicative of those children withdrawing from social situations in which they are less capable of applying intelligence and effort to a positive response in the situation. More research into the association between prosocial inhibition, prosocial activation, and inhibitory control is necessary to clarify these hypotheses.

Contributions to School Readiness. The final purpose of my investigation was to explore the ways in which motoric and verbal IC differentially relate to school readiness outcomes. Academic competence and emerging mathematical abilities related to both verbal and motoric IC, even when controlling for intelligence. What's more, there was no moderating role of intelligence in the association between IC and these school readiness outcomes. These findings reveal that IC is important to school readiness outcomes at all levels of intelligence and that IC plays an important role in these outcomes over and above that of intelligence. This also suggests that the unique importance of "self-discipline" to children's school grades (Duckworth and Seligman, 2005) may begin early in the preschool-aged years. Interestingly, however, children's emergent literacy, when controlling for intelligence, related to motoric, but not verbal, IC. Key literature determining the association between IC and emergent literacy has made use of only motoric IC tasks (e.g., Blair & Razza, 2007, Ponitz et al., 2009, Welsh et al., 2010). In fact, to the best of my knowledge, this is the first study to compare the strength of the association of emergent literacy with both verbal and motoric IC. Therefore, there is no research precedent for describing this differential association. However, it is likely that children excelling in motoric IC, as hypothesized, have been better able to sit still and to take in information, thus improving their vocabulary and their early word recognition.

Limitations, Future Directions, and Conclusions

IC, the ability to inhibit irrelevant thoughts and behaviors, is a key executive function important to children's social and academic development. In response to the task impurity problem, researchers have created dichotomies among tasks according to key task characteristics. However, these dichotomies, although conceptually distinct, often overlap in practice. This investigation enhances the IC literature by examining a unique, non-overlapping dichotomy, that of whether task demands require children to inhibit a verbal response or a motoric response. Results of the study revealed that, although EF in early childhood has traditionally been considered to fall on one factor, verbal and motoric IC are, in fact, distinguishable composites. Findings replicate previous research, regarding the ways in which IC relates to electrophysiology temperament, language, intelligence, and social and academic outcomes while also contributing insight into the ways in which verbal and motoric IC differentially relate to each of these characteristics. Findings also underscore the importance of including in early childhood IC investigations a large battery of tasks.

Limitations and Future Directions. Despite the importance of this investigation, it is subject to some limitations that should be addressed with future research. First, research participants were part of a relatively homogenous sample, with the majority of children having highly-educated Caucasian parents. Young, low-income children, however, have disproportionately poor executive functions (Diamond, Barnett, Thomas, & Munro, 2012; Noble, Norman, & Farah, 2005; Noble, McCandliss, & Farah, 2007). Therefore, future research in a more diverse population would likely allow for investigation of IC in children who would likely demonstrate a wider range of characteristics. Second, the study would benefit by replications as a longitudinal investigation. It is difficult to draw strong conclusions about the antecedents and consequences of IC when data on both were collected at the same time as was IC task performance data. Future research should collect data on IC and its correlates at multiple times throughout childhood in order to determine if the effects of early antecedents have enduring effects on IC and if, in turn, IC has enduring effects on childhood social and academic outcomes. Third, the positive association of IC with shyness and social inhibition was unexpected and was, therefore, not explored in great depth. Future research is needed to explore the direction of causation of the association and should include multiple measures of each construct in order to better reflect children's shyness and social inhibition in a variety of situations, with and without parents present.

Fourth, in order to create a laboratory protocol short enough to be suitable for work with 4-year-old children, the current investigation explored IC using only tasks that fall on the complex, conflict, and cool dimensions of the traditional IC dichotomies. However, the verbal vs. motoric IC task distinction could behave differently when explored on the simple, delay, and hot side of these same dichotomies. Fifth, although the current investigation was sufficiently powered, a number of children refused to wear the EEG cap, which may explain some of the lack of effects that we see in regressions involving electrophysiological data. Future research with more EEG data could give more insight into the ways in which brain development affects verbal and motoric IC. Finally, this new task distinction deserves to be explored in greater depth with research examining associations with a wider range of IC correlates. For example, future research could explore the ways in which EEG coherence or heart rate variability differentially relate to verbal and motoric IC. All future IC investigations should continue to explore the verbal and motoric IC task distinction using a large battery of such IC tasks.

Conclusions. In conclusion, my investigation contributes to the IC literature in a number of important ways. First and foremost, it contributes by examining the important new distinction between IC tasks requiring children to withhold a dominant verbal response and those requiring children to instead inhibit a dominant bodily movement. Future research should continue to examine this dichotomy, particularly in longitudinal investigations of a more diverse group of children, paying particular attention to children's social inhibition and shyness as well as other IC correlates, and using similarly large protocols of the same and/or different IC tasks.

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Figures

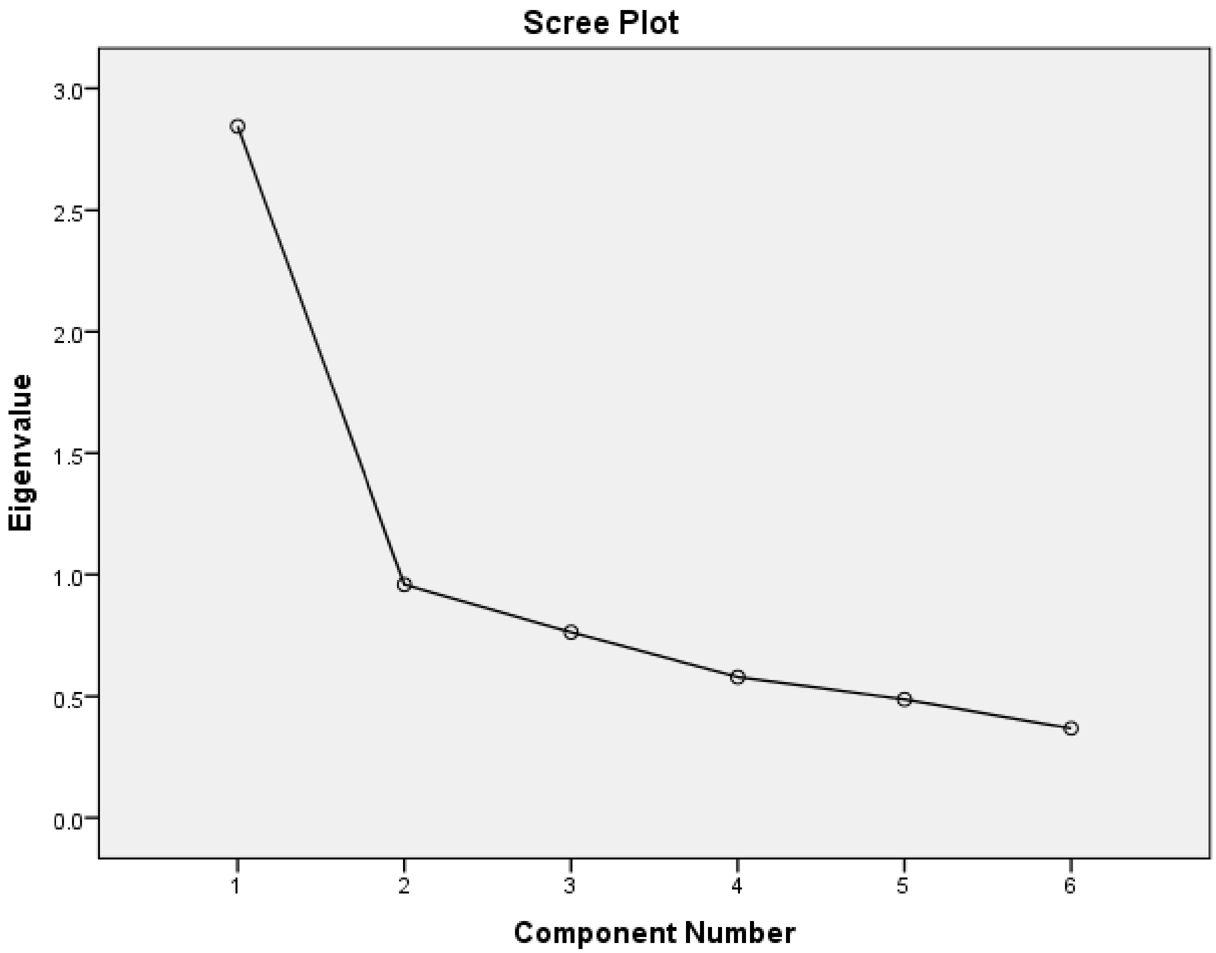


Figure 1. Scree Plot Associated with Principal Components Analysis, Indicating a 2-Component Solution.

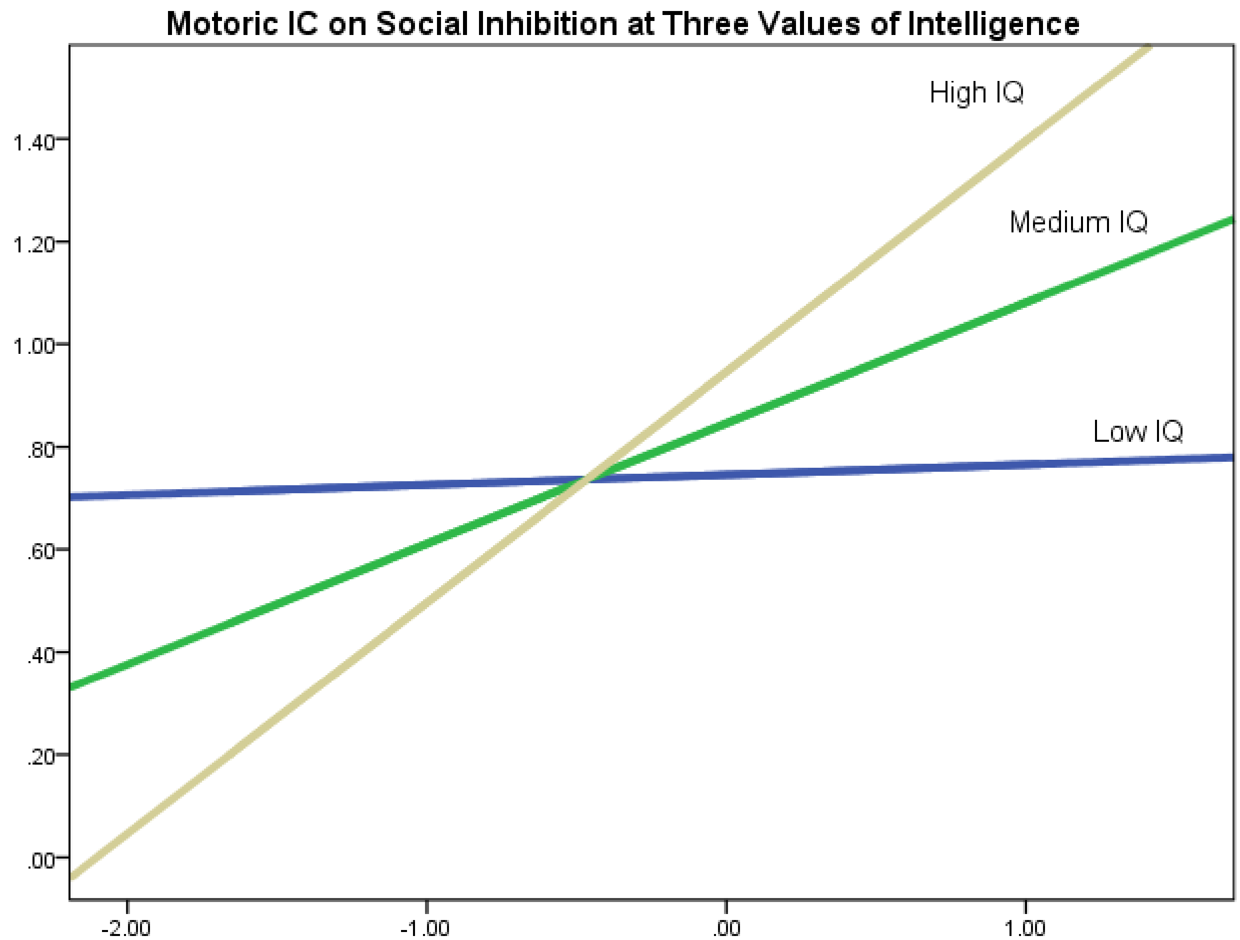


Figure 2. Motoric IC on Social Inhibition at Three Values of Intelligence, Showing the Interaction between IC and IQ in Predicting Social Inhibition.

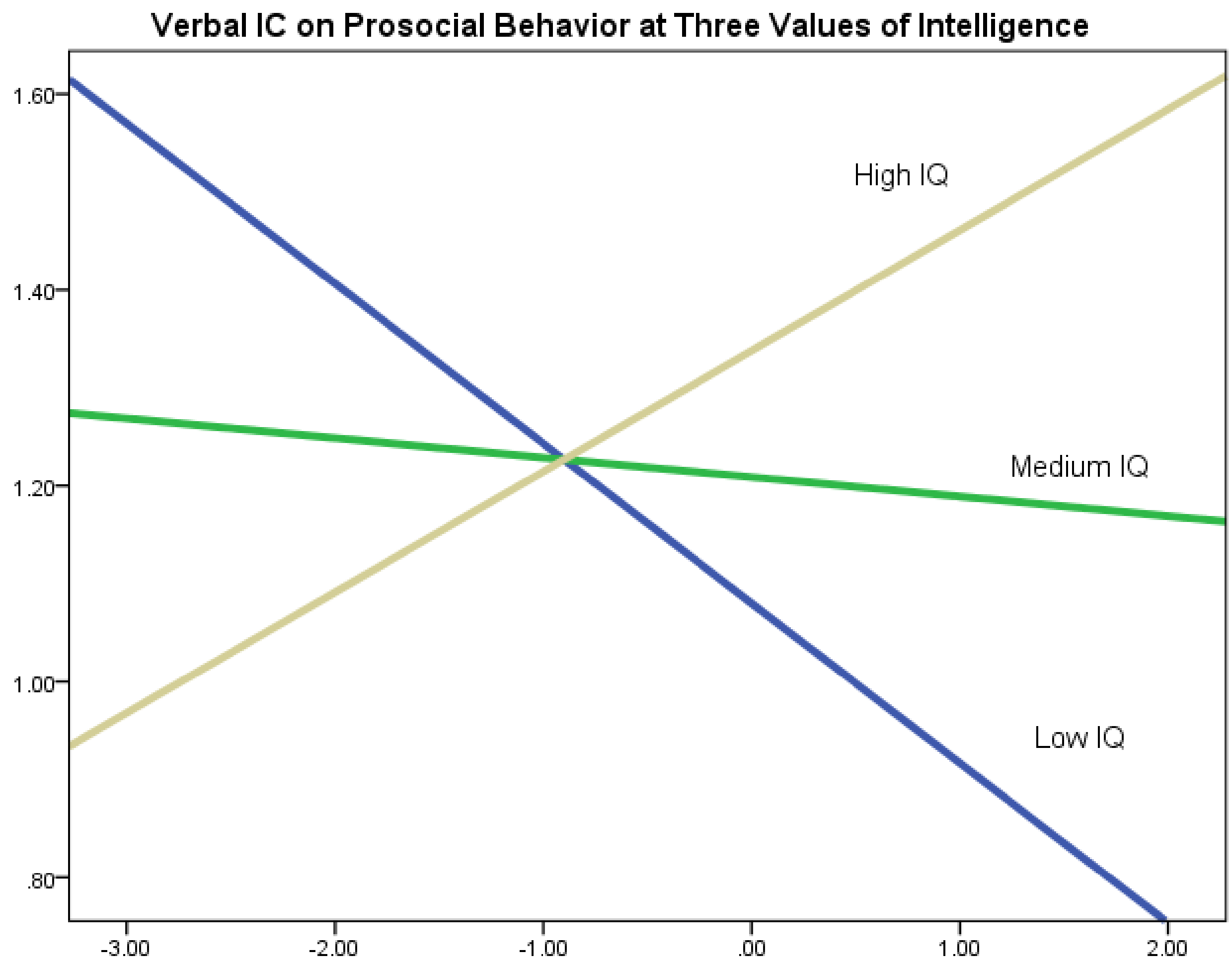


Figure 3. Verbal IC on Prosocial Behavior at Three Values of Intelligence, Showing the Interaction between IC and IQ in Predicting Prosocial Behavior.

Tables

Table 1
Summary of Tasks Described in Literature Review, Along with Classification According to Traditional and Unique Dichotomies.

Task	Correct Response	Simple/ Complex	Conflict/ Delay	Hot/ Cool	Verbal/ Motoric
Grass-Snow	Touch white paper when E says "grass", green when E says "snow".	Complex	Conflict	Cool	Motoric
Tapping	Tap once when E taps twice, vice versa.	Complex	Conflict	Cool	Motoric
Hand Game	Present a fist when E presents flat hand, vice versa.	Complex	Conflict	Cool	Motoric
Less is More	Point to array of fewer treats in order to earn more.	Complex	Conflict	Hot	Motoric
Yes-No	Say "yes" to E's head shake, "no" to E's nod.	Complex	Conflict	Cool	Verbal
Day-Night	Say "day" to picture of moon and stars, "night" to picture of sun on white background.	Complex	Conflict	Cool	Verbal
Silly Sounds Stroop	Say "woof" in response to a cat picture, and "meow" in response to a dog picture.	Complex	Conflict	Cool	Verbal
Gift Delay	Do not peek as E noisily wraps a gift.	Simple	Delay	Hot	Motoric
Snack Delay	Hold a treat to the tongue without eating it for a specified amount of time.	Simple	Delay	Hot	Motoric
Marshmallow Delay	Refrain from eating one marshmallow in order to earn two for later.	Simple	Delay	Hot	Motoric

Note: E = "experimenter"; Bolded tasks are used in this protocol.

Table 2

Descriptive Statistics for Variables of Interest

Task Type	Task	*M*	*SD*	Min.	Max.	*n*
Verbal IC	Day-Night	.60	.27	0.00	1.00	69
	Yes-No	.72	.21	0.06	1.00	69
	Silly-Sounds	.63	.24	0.00	1.00	69
Motoric IC	Grass-Snow	.75	.25	0.00	1.00	69
	Hand Game	.86	.16	0.47	1.00	69
	Tapping Task	.68	.27	0.13	1.00	68
Language	PPVT Std.	111.67	18.35	60.00	151.00	69
Intelligence	KBIT Verbal	105.60	16.25	60.00	128.00	68
	KBIT Nonverbal	98.88	13.64	66.00	127.00	68
	KBIT Composite	103.01	14.33	68.00	131.00	68
School Readiness	WJ Letter-Word Identification	10.49	6.30	1.00	38.00	69
	WJ Applied Problems	14.09	3.76	7.00	22.00	69
	HBQ Academic Functioning	4.68	.99	2.50	6.13	20
Social Functioning	HBQ Peer acceptance	3.60	.42	1.63	4.00	68
	HBQ Bullied by Peers	1.32	.48	1.00	3.33	68
	HBQ Prosocial Behavior	1.26	.33	0.55	1.90	69
	HBQ Overt Hostility	.33	.31	0.00	1.50	69
	HBQ Relational Aggression	.24	.28	0.00	1.17	68
	HBQ Asocial with Peers	.33	.28	0.00	1.00	69
	HBQ Social Inhibition	.93	.48	0.00	2.00	69
Temperament	CBQ IC Scale	4.67	.89	2.50	6.67	69

Note: All IC scores are based on proportion correct. PPVT, KBIT, and WJ are standardized scores by age. HBQ and CBQ scores are based on an average of questions rated on Likert-type scales. The HBQ academic functioning scale is optional for parents of preschool-aged children, but parents could elect to complete this scale

Table 3
Correlations Among IC Tasks and Composites.

	DN	YN	SS	GS	HG	TT	Verb.	Motor.
Day-Night	1							
Yes-No	$.226^{*}$	1						
Silly Sounds	$.468^{**}$	$.481^{**}$	1					
Grass-Snow	$.317^{**}$	$.390^{**}$	$.372^{**}$	1				
Hand Game	$.222^{*}$	$.230^{*}$	$.263^{*}$	$.397^{**}$	1			
Tapping Task	$.343^{**}$	$.434^{**}$	$.365^{**}$	$.518^{**}$	$.492^{**}$	1		
Verbal IC Composite	$.732^{**}$	$.738^{**}$	$.843^{**}$	$.467^{**}$	$.309^{**}$	$.493^{**}$	1	
Motoric IC Composite	$.375^{**}$	$.434^{**}$	$.411^{**}$	$.795^{**}$	$.786^{**}$	$.837^{**}$	$.527^{**}$	1

Note: The above represent one-tailed correlations between and among tasks and composites.
** = p <.01, * = p <.05, $^{+}$ = p <. 10

Table 4

Component Loadings of Verbal IC and Motoric IC in a Two-Component Solution

Type of IC	Task	Component 1	Component 2
Verbal IC	Day-Night	.265	**.788**
	Yes-No	.529	**.642**
	Silly Sounds	.419	**.851**
Motoric IC	Grass-Snow	**.744**	.496
	Hand Game	**.806**	.203
	Tapping Task	**.824**	.498

Note: The above represent loadings of each task onto two promax rotated components. Bolded are values indicating the stronger loading.

Table 5
Results of Hierarchical Regression Analyses Predicting Verbal IC Performance from Frontal Electrophysiology at Baseline and Task

	B	SE(B)	β	*t*	*p*	sR^2
Predicted: Day-Night Performance						
Lateral frontal baseline EEG	.12	.15	.16	.82	.418	<.01
Lateral frontal task EEG	-.16	.13	-.26	-1.30	.200	.03
$R^2 = .03$, $F\ (2, 57) = .87$, $p = .424$						
Predicted: Yes-No Performance						
Lateral frontal baseline EEG	.33	.15	.51	2.24	.029	.02
Lateral frontal task EEG	-.27	.13	-.47	-2.06	.044	.07
$R^2 = .09$, $F\ (2, 54) = 2.58$, $p = .085$						
Predicted: Silly Sounds Performance						
Lateral frontal baseline EEG	.18	.14	.25	1.27	.210	.03
Lateral frontal task EEG	-.08	.13	-.13	-.63	.533	<.01
$R^2 = .03$, $F\ (2, 57) = .93$, $p = .399$						
Predicted: Verbal IC Composite Performance						
Lateral frontal baseline EEG	.75	.52	.34	1.45	.153	.01
Lateral frontal task EEG	-.56	.48	-.27	-1.16	.252	.03
$R^2 = .04$, $F\ (2, 57) = 1.05$, $p = .356$						

Note. Baseline and task EEG independently explain variance in Yes-No task performance. Neither variable explains significant variance in any other verbal IC task.

Table 6

Results of Hierarchical Regression Analyses Predicting Motoric IC Performance from Frontal Electrophysiology at Baseline and Task

	B	SE(B)	β	*t*	*p*	sR^2
Predicted: Grass-Snow Performance						
Lateral frontal baseline EEG	.24	.16	.31	1.52	.134	<.01
Lateral frontal task EEG	-.21	.14	-.32	-1.55	.126	.05
$R^2 = .05$, $F(2, 57) = 1.33$, $p = .272$						
Predicted: Hand Game Performance						
Lateral frontal baseline EEG	.13	.09	.28	1.53	.131	<.01
Lateral frontal task EEG	-.13	.08	-.32	-1.76	.085	.05
$R^2 = .05$, $F(2, 57) = 1.62$, $p = .207$						
Predicted: Tapping Task Performance						
Lateral frontal baseline EEG	.24	.14	.31	1.69	.097	.02
Lateral frontal task EEG	-.20	.14	-.26	-1.41	.164	.03
$R^2 = .05$, $F(2, 56) = 1.47$, $p = .238$						
Predicted: Motoric IC Composite Performance						
Lateral frontal baseline EEG	1.20	.48	.51	2.50	.016	.01
Lateral frontal task EEG	-1.21	.47	-.53	-2.61	.012	.10
$R^2 = .11$, $F(2, 57) = 3.65$, $p = .032$						

Note. Baseline and task EEG independently explain variance in Motoric IC task performance as a whole. Task EEG shows a trend toward predicting Hand Game performance. Neither variable explains significant variance in any other motoric IC task.

Table 7
Correlations Between Verbal and Motoric IC Tasks and Composites and Language, Intelligence, and Temperament

Type of Task	IC Task	Language	Verbal IQ	Nonverbal IQ	IQ Composite	CBQ IC
Verbal IC	Day-Night	$.378^{**}$	$.355^{**}$	$.173^{+}$	$.339^{**}$	$.260^{*}$
	Yes-No	.139	$.189^{+}$	$.174^{+}$	$.233^{*}$	$.196^{+}$
	Silly Sounds	$.352^{**}$	$.350^{**}$	$.158^{+}$	$.323^{**}$	$.254^{*}$
	Composite	$.376^{**}$	$.388^{**}$	$.220^{*}$	$.389^{**}$	$.307^{**}$
Motoric IC	Grass-Snow	$.310^{**}$	$.255^{*}$	$.423^{**}$	$.389^{**}$	$.297^{**}$
	Hand Game	$.229^{*}$	$.213^{*}$	$.208^{*}$	$.262^{*}$	$.326^{**}$
	Tapping Task	$.245^{*}$	$.353^{**}$	$.505^{**}$	$.523^{**}$	$.261^{*}$
	Composite	$.332^{**}$	$.346^{**}$	$.473^{**}$	$.491^{**}$	$.379^{**}$

Note: Language and intelligence scores are standardized scores from the PPVT and the KBIT verbal intelligence scale, nonverbal intelligence scale, and intelligence composite. CBQ IC is a scale score on the parent-reported CBQ. $^{**} = p <.01$, $^{*} = p <.05$, $^{+} = p <. 10$

Table 8

Z-test of Correlations between IC Tasks and Language

	DN	YN	SS	GS	HG	TT	Verb.	Motor.
Day-Night	--							
Yes-No	1.48^{+}	--						
Silly Sounds	.17	1.31^{+}	--					
Grass-Snow	.44	1.04	.27	--				
Hand Game	.95	.54	.77	.50	--			
Tapping Task	.84	.63	.67	.40	.10	--		
Verbal IC Composite	--	--	--	--	--	--	--	
Motoric IC Composite	--	--	--	--	--	--	.29	--

Note: The above represent z-tests of one-tailed correlations between tasks and composites and language. $^{**} = p < .01$, $^{*} = p < .05$, $^{+} = p < .10$

Table 9

Z-test of Correlations between IC Tasks and Intelligence (Composite of Verbal and Nonverbal)

	DN	YN	SS	GS	HG	TT	Verb.	Motor.
Day-Night	--							
Yes-No	.66	--						
Silly Sounds	.10	.56	--					
Grass-Snow	.33	.99	.43	--				
Hand Game	.48	.18	.38	.81	--			
Tapping Task	1.29^{+}	1.95^{*}	1.39^{+}	.96	1.77^{*}	--		
Verbal IC Composite	--	--	--	--	--	--	--	
Motoric IC Composite	--	--	--	--	--	--	.72	--

Note: The above represent z-tests of one-tailed correlations between tasks and composites and KBIT Standardized IQ composite. ** = p <.01, * = p <.05, $^{+}$ = p <. 10

Table 10

Z-test of Correlations between IC Tasks and Intelligence (Verbal and Nonverbal)

	DN	YN	SS	GS	HG	TT	Verb.	Motor.
Day-Night	--	.01	.09	1.58^{+}	-21	2.16^{*}		
Yes-No	1.03	--	.09	1.57^{+}	.20	2.16^{*}		
Silly Sounds	.03	.99	--	1.66^{*}	.29	2.25^{*}		
Grass-Snow	.63	.40	.60	--	1.37^{+}	.59		
Hand Game	.88	.14	.85	.25	--	1.96^{*}		
Tapping Task	.01	1.01	.02	.61	.87	--		
Verbal IC Composite	--	--	--	--	--	--	--	1.65^{*}
Motoric IC Composite	--	--	--	--	--	--	.28	--

Note: The above represent z-tests of one-tailed correlations between tasks and composites and KBIT Verbal and Nonverbal scales. Values for correlations with the nonverbal scale can be found in the upper triangle. Values for correlations with verbal scales can be found in the lower triangle. ** = p <.01, * = p <.05, $^{+}$ = p <. 10

Table 11

Z-test of Correlations between IC Tasks and Temperament (IC)

	DN	YN	SS	GS	HG	TT	Verb.	Motor.
Day-Night	--							
Yes-No	.39							
Silly Sounds	.04	.35	--					
Grass-Snow	.23	.62	.27	--				
Hand Game	.41	.80	.45	.18	--			
Tapping Task	.01	.39	.04	-.22	.41	--		
Verbal IC Composite	--	--	--	--	--	--	--	
Motoric IC Composite	--	--	--	--	--	--	.47	--

Note: The above represent z-tests of one-tailed correlations between tasks and composites and CBQ IC Scale.

** = p <.01, * = p <.05, $^{+}$ = p <. 10

Table 12

Correlations among Verbal and Motoric IC Tasks and Composites and Non-IC and Non-IC Aspects of Temperament

	Verbal IC				Motoric IC			
	Day-Night	Yes-No	Silly Sounds	Verbal IC Comp.	Grass-Snow	Hand Game	Tapping Task	Motoric IC Comp.
Activity Level	-.109	-.290**	-.250*	-.280**	-.345**	-.286**	-.354**	-.413**
Anger	-.211*	-.032	-.082	-.141	-.138	.074	-.086	-.072
Approach	.257*	-.099	.031	.082	-.060	.061	-.075	-.033
Attention Focusing	-.077	.132	.002	.025	.160+	.254*	.189+	.262*
Discomfort	.136	.045	.075	.111	.095	-.025	.153	.083
Falling Reactivity/ Soothability	.215*	-.211*	-.019	-.007	-.087	-.103	.122	-.013
Fear	.098	.199+	.252*	.237*	.004	.163+	.135	.114
High Intensity Pleasure	-.168+	-.151	-.274*	-.257*	-.325**	-.146	-.362**	-.351**
Impulsivity	-.210*	-.192+	-.156+	-.241*	-.434**	-.291**	-.276*	-.420**
Low Intensity Pleasure	.050	.044	.144	.103	-.035	.176+	.238*	.156+
Perceptual Sensitivity	.077	-.023	.050	.045	.134	-.061	.148	.092
Sadness	-.063	.148	.002	.038	.107	.140	-.004	.099
Shyness	.052	.287**	.247*	.253*	.235*	.192+	.175+	.243*
Smiling	.091	-.126	-.046	-.035	-.175+	-.050	.010	-.078
Negative Affect	-.055	.177+	.100	.096	.048	.140	.046	.081
Surgency	-.165+	-.293**	-.291**	-.324**	-.416**	-.286**	-.355**	-.441**

Note: Values for IC scale and EC factor can be found in Table 7. ** = p <.01, * = p <.05, + = p <. 10

Table 13

Results of Hierarchical Regression Analyses Predicting Verbal IC Performance from Frontal Electrophysiology at Baseline and Task, Temperament, and Language

	B	SE(B)	β	*t*	*p*	sR^2
Predicted: Day-Night Performance						
Lateral frontal baseline EEG	.06	.15	.09	.43	.669	<.01
Lateral frontal task EEG	-.11	.13	-.18	-.91	.369	.03
CBQ IC	.02	.04	.08	.61	.545	.02
PPVT Standard	.00	.00	.25	1.90	.063	.06
$R^2 = .11$, F (4, 55) = 1.68, $p = .168$						
Predicted: Yes-No Performance						
Lateral frontal baseline EEG	.32	.15	.50	2.11	.040	.02
Lateral frontal task EEG	-.26	.14	-.44	-1.88	.066	.07
CBQ IC	.02	.03	.09	.63	.535	.01
PPVT Standard	.01	.00	-.05	-.33	.740	.00
$R^2 = .10$, F (4, 52) = 1.36, $p = .261$						
Predicted: Silly Sounds Performance						
Lateral frontal baseline EEG	.10	.14	.14	.74	.465	.03
Lateral frontal task EEG	.00	.12	.00	-.02	.983	.01
CBQ IC	.04	.04	.14	1.11	.272	.05
PPVT Standard	.00	.00	.30	2.31	.025	.08
$R^2 = .16$, F (4, 55) = 2.61, $p = .045$						
Predicted: Verbal IC Composite Performance						
Lateral frontal baseline EEG	.51	.51	.22	.99	.326	.01
Lateral frontal task EEG	-.32	.48	-.15	-.66	.510	.02
CBQ IC	.13	.11	.16	1.22	.230	.04
PPVT Standard	.01	.00	.22	1.66	.103	.04
$R^2 = .12$, F (4, 55) = 1.95, $p = .115$						

Note. The combination of 4 variables predicts Silly Sounds performance. When controlling for EEG and temperament, language explains unique variance in Silly Sounds performance, and marginally explains variance in Day-Night performance.

Table 14

Results of Hierarchical Regression Analyses Predicting Motoric IC Performance from Frontal Electrophysiology at Baseline and Task, Temperament, and Language

	B	SE(B)	β	*t*	*p*	sR^2
Predicted: Grass-Snow Performance						
Lateral frontal baseline EEG	.21	.15	.27	1.37	.175	.00
Lateral frontal task EEG	-.18	.13	-.28	-1.44	.157	.04
CBQ IC	.06	.04	.22	1.70	.095	.08
PPVT Standard	.00	.00	.25	1.95	.057	.06
$R^2 = .18$, F (4, 55) = 3.07, $p = .024$						
Predicted: Hand Game Performance						
Lateral frontal baseline EEG	.11	.09	.25	1.31	.195	.00
Lateral frontal task EEG	-.11	.08	-.26	-1.43	.160	.05
CBQ IC	.04	.12	.21	1.55	.126	.05
PPVT Standard	.00	.00	.05	.34	.738	.00
$R^2 = .10$, F (4, 55) = 1.56, $p = .197$						
Predicted: Tapping Task Performance						
Lateral frontal baseline EEG	.21	.15	.28	1.48	.146	.01
Lateral frontal task EEG	-.18	.14	-.23	-1.25	.216	.04
CBQ IC	.04	.04	.13	.94	.352	.02
PPVT Standard	.00	.00	.12	.89	.377	.01
$R^2 = .09$, F (4, 54) = 1.23, $p = .295$						
Predicted: Motoric IC Composite Performance						
Lateral frontal baseline EEG	1.03	.47	.44	2.20	.032	.10
Lateral frontal task EEG	-1.02	.45	-.45	-2.26	.028	.01
CBQ IC	.22	.11	.25	2.02	.049	.09
PPVT Standard	.01	.01	.17	1.34	.187	.03
$R^2 = .22$, F (4, 55) = 3.96, $p = .007$						

Note. The combination of variables predicts significant variance in the Motric IC composite as well as Grass-Snow performance. Baseline and task EEG and temperament uniquely predict variance in the Motoric IC composite. Temperament and language marginally predict variance in Grass-Snow performance.

Table 15

Results of Hierarchical Regression Analyses Predicting Frontal Electrophysiology, Temperament, and Language from Verbal and Motoric IC and their Interaction

	B	SE(B)	β	*t*	*p*	sR^2
Predicted: Lateral Frontal baseline EEG						
Motoric IC Composite	.02	.07	.04	.25	.807	.02
Verbal IC Composite	.06	.07	.14	.88	.382	.01
Motoric x Verbal IC Interaction	-.02	.08	-.03	-.22	.828	.00
$R^2 = .03$, $F\ (3, 57) = .56$, $p = .641$						
Predicted: CBQ IC						
Motoric IC Composite	.31	.16	.28	1.96	.054	.14
Verbal IC Composite	.17	.15	.15	1.11	.270	.02
Motoric x Verbal IC Interaction	-.07	.18	-.05	-.37	.709	.00
$R^2 = .16$, $F\ (3, 65) = 4.16$, $p = .009$						
Predicted: PPVT Standard						
Motoric IC Composite	3.35	3.23	.16	1.10	.276	.11
Verbal IC Composite	6.65	3.17	.28	2.10	.040	.06
Motoric x Verbal IC Interaction	-2.07	3.77	-.07	-.55	.584	.00
$R^2 = .17$, $F\ (3, 65) = 4.43$, $p = .007$						

Note. The combination of verbal and motoric IC and their interaction predicts significant variance in temperament and language. Verbal IC predicts significant variance in language above and beyond the contribution of Motoric IC.

Table 16

Correlations between verbal and motoric IC tasks and composites and social and academic outcome variables

Type of Task	IC Task	Peer Acceptance	Bullied	Prosocial	Overt Hostility	Relational Aggression	Asocial	Social Inhibition	Academic Competence	Emergent Literacy	Math
Verbal IC	Day-Night	.145	-.203*	.077	-.176^{+}	-.271*	.025	.306**	.483*	.021	.313*
		-.025	*-.132*	*-.081*	*-.002*	*-.204**	*-.018*	*.232**	*.268*	*-.196*$^{+}$	*.116*
	Yes-No	.011	-.108	.079	-.047	-.139	.195^{+}	.236*	.530**	.214*	.372**
		-.004	*-.101*	*.025*	*.017*	*-.150*	*.144*	*.181*$^{+}$	*.539**	*.123*	*.286***
	Silly Sounds	-.007	.044	.088	-.065	-.153	.208*	.270*	.527**	.103	.390**
		-.008	*.057*	*.034*	*-.006*	*-.177**	*.119*	*.217**	*.580***	*-.056*	*.230**
	Composite	.064	-.116	.106	-.124	-.245*	.185^{+}	.351**	.666**	.146	.464**
		-.016	*-.080*	*-.009*	*.004*	*-.237**	*.111*	*.280**	*.651***	*-.053*	*.285***
Motoric IC	Grass-Snow	.250*	-.198	.075	-.231*	-.321**	.177^{+}	.335**	.309^{+}	.209*	.396**
		.207*	*-.155*	*-.055*	*-.123*	*-.302***	*.127*	*.265**	*.255*	*.029*	*.208**
	Hand Game	.003	-.042	-.021	-.119	-.179^{+}	.405**	.336**	.558**	.287**	.294**
		-.131	*.016*	*-.128*	*.005*	*-.114*	*.409***	*.296***	*.409*$^{+}$	*.184*$^{+}$	*.174*$^{+}$
	Tapping Task	.040	-.032	.175^{+}	-.113	-.046	.344**	.340**	.486*	.374**	.497**
		.045	*.004*	*.078*	*-.005*	*-.040*	*.284**	*.242**	*.397*$^{+}$	*.209**	*.291***
	Composite	.157	-.129	.109	-.217*	-.253*	.369*	.419**	.569**	.366**	.493**
		.049	*-.059*	*-.051*	*-.054*	*-.200*$^{+}$	*.359***	*.350***	*.433**	*.182*$^{+}$	*.289***

Note: Social measures are from the parent-reported HBQ. Academic Competence also comes from the HBQ. Emerging Literacy and Math scores are from the Woodcock Johnson. First listed score represents a one-tailed correlation. Scores in italics are partial one-tailed correlations, controlling for KBIT intelligence. ** = p <.01, * = p <.05, $^{+}$ = p <. 10

Table 17

Z-test of Correlations between IC Tasks and Social Outcomes (Relational Aggression and Asocial)

	DN	YN	SS	GS	HG	TT	Verb.	Motor.
Day-Night	--	.89	.75	.79	2.46*	1.68*		
Yes-No	.30	--	.14	.09	1.57+	.80		
Silly Sounds	.15	.15	--	.04	1.71*	.94		
Grass-Snow	.57	.87	.72	--	1.67*	.89		
Hand Game	.50	.20	.35	1.07	--	.77		
Tapping Task	.91	.60	.75	1.48+	.40	--		
Verbal IC Composite	--	--	--	--	--	--	--	1.44+
Motoric IC Composite	--	--	--	--	--	--	.21	--

Note: The above represent z-tests of one-tailed partial correlations, controlling for KBIT intelligence between tasks and composites and HBQ Relational Aggression (lower triangle) and Asocial (upper triangle) scales. ** = p <.01, * = p <.05, + = p <. 10

Table 18

Z-test of Correlations between IC Tasks and Social Outcomes (Social Inhibition)

	DN	YN	SS	GS	HG	TT	Verb.	Motor.
Day-Night	--							
Yes-No	.29	--						
Silly Sounds	.09	.20	--					
Grass-Snow	.19	.48	.28	--				
Hand Game	.37	.66	.46	.46	--			
Tapping Task	.06	.35	.14	.13	.32	--		
Verbal IC Composite	--	--	--	--	--	--	--	
Motoric IC Composite	--	--	--	--	--	--	.42	--

Note: The above represent z-tests of one-tailed partial correlations, controlling for KBIT intelligence between tasks and composites and HBQ Social Inhibition scale. $^{**} = p < .01$, $^{*} = p < .05$, $^{+} = p < .10$

Table 19

Z-test of Correlations between IC Tasks and Academic Outcomes (Academic Competence and Emerging Literacy)

	DN	YN	SS	GS	HG	TT	Verb.	Motor.
Day-Night	--	.1.78*	.79	1.26	2.12*	2.27**		
Yes-No	.80	--	.99	.52	.35	.49		
Silly Sounds	.95	.15	--	.47	1.34+	1.48+		
Grass-Snow	.03	.84	.28	--	.87	1.01		
Hand Game	.39	.41	.56	.43	--	.14		
Tapping Task	.36	.45	.59	.39	.04	--		
Verbal IC Composite	--	--	--	--	--	--	--	1.31+
Motoric IC Composite	--	--	--	--	--	--	.77	--

Note: The above represent z-tests of one-tailed partial correlations, controlling for KBIT intelligence between tasks and composites and HBQ Academic Competence (lower triangle) and WJ Emerging Literacy (upper triangle) scales. ** = p <.01, * = p <.05, + = p <. 10

Table 20

Z-test of Correlations between IC Tasks and Academic Outcomes (Math)

	DN	YN	SS	GS	HG	TT	Verb.	Motor.
Day-Night	--							
Yes-No	.98	--						
Silly Sounds	.65	.33	--					
Grass-Snow	.52	.46	.13	--				
Hand Game	.33	.65	.32	.19	--			
Tapping Task	1.01	.03	.36	.49	.68	--		
Verbal IC Composite	--	--	--	--	--	--	--	
Motoric IC Composite	--	--	--	--	--	--	.02	--

Note: The above represent z-tests of one-tailed partial correlations, controlling for KBIT intelligence between tasks and composites and WJ Math. $^{**} = p < .01$, $^{*} = p < .05$, $^{+} = p < .10$

Table 21
Results of Hierarchical Regression Analyses Determining a Potential Moderation Model with Motoric and Social Variables

	B	SE(B)	β	*t*	*p*	sR^2
Predicted: HBQ Peer Acceptance						
Motoric IC Composite	.06	.07	.11	.78	.434	.02
KBIT IQ Standard	.00	.00	.00	-.03	.980	.00
Motoric IC x KBIT Interaction	-.07	.06	-.15	-1.10	.275	.02
R^2 = .02, F (3, 63) = .917, p = .318						
Predicted: HBQ Bullied						
Motoric IC Composite	-.05	.08	-.08	-.61	..544	.02
KBIT IQ Standard	.00	.00	-.06	-.38	.709	.00
Motoric IC x KBIT Interaction	.03	.07	.06	.44	.664	.00
R^2 = .02, F (3, 63) = .52, p = .672						
Predicted: HBQ Prosocial						
Motoric IC Composite	-.01	.06	-.04	-.26	.793	.01
KBIT IQ Standard	.01	.00	.27	1.86	.067	.06
Motoric IC x KBIT Interaction	-.01	.05	-.03	-.22	.828	.00
R^2 = .07, F (3, 64) = 1.60, p = .199						
Predicted: HBQ Overt Hostility						
Motoric IC Composite	-.04	.05	-.10	-.72	.476	.05
KBIT IQ Standard	-.00	.00	-.16	1.09	.278	.03
Motoric IC x KBIT Interaction	.05	.04	.16	1.22	.226	.02
R^2 = .10, F (3, 64) = 2.35, p = .081						
Predicted: HBQ Relational Aggression						
Motoric IC Composite	-.10	.05	-.28	-2.09	.040	.07
KBIT IQ Standard	.00	.00	.00	.01	.993	.00
Motoric IC x KBIT Interaction	-.04	.04	-.13	-.99	.323	.01
R^2 = .08, F (3, 63) = 1.88, p = .142						
Predicted: HBQ Asocial						
Motoric IC Composite	.13	.05	.38	2.82	.006	.13
KBIT IQ Standard	.00	.00	.00	.02	.987	.00
Motoric IC x KBIT Interaction	.02	.04	.07	.57	.572	.00
R^2 = .14, F (3, 64) = 3.34, p = .025						
Predicted: HBQ Social Inhibition						
Motoric IC Composite	.24	.07	.40	3.24	.002	.18

KBIT IQ Standard	.01	.00	.21	1.71	.092	.01
Motoric IC x KBIT Interaction	.17	.06	.32	2.81	.006	.09
$R^2 = .28$, $F\ (3, 64) = 8.13$, $p < .001$						

Note. The interaction term describes unique variance in Social Inhibition.

Table 22

Results of Hierarchical Regression Analyses Determining a Potential Moderation Model with Motoric and Academic Variables

	B	SE(B)	β	*t*	*p*	sR^2
Predicted: HBQ Academic Competence						
Motoric IC Composite	.56	.25	.49	2.28	.038	.33
KBIT IQ Standard	.00	.02	-.01	-.05	.958	.02
Motoric IC x KBIT Interaction	-.40	.24	-.37	1.70	.111	.11
$R^2 = .46$, $F\ (3, 15) = 4.18$, $p = .025$						
Predicted: WJ Emerging Literacy						
Motoric IC Composite	1.61	.99	.21	1.61	.110	.13
KBIT IQ Standard	.15	.06	.33	2.50	.015	.08
Motoric IC x KBIT Interaction	.32	.84	.05	.38	.706	.00
$R^2 = .21$, $F\ (3, 65) = 4.16$, $p = .009$						
Predicted: WJ Math						
Motoric IC Composite	1.16	.50	.26	2.31	.024	.24
KBIT IQ Standard	.11	.03	.43	3.71	.000	.16
Motoric IC x KBIT Interaction	-.34	.43	-.08	-.81	.424	.00
$R^2 = .41$, $F\ (3, 64) = 14.41$, $p < .001$						

Note. The interaction term did not describe unique variance in any school readiness outcome.

Table 23
Results of Hierarchical Regression Analyses Determining a Potential Moderation Model with Verbal and Social Variables

	B	SE(B)	β	*t*	*p*	sR^2
Predicted: HBQ Peer Acceptance						
Verbal IC Composite	.00	.07	.00	-.03	.975	.00
KBIT IQ Standard	.00	.00	.14	.90	.374	.01
Verbal IC x KBIT Interaction	.04	.08	-.07	.49	.626	.00
$R^2 = .02$, F (3, 63) = .31, $p = .815$						
Predicted: HBQ Bullied						
Verbal IC Composite	-.06	.08	-.10	-.73	.471	.01
KBIT IQ Standard	.00	.00	-.03	-.22	.826	.01
Verbal IC x KBIT Interaction	.07	.09	.11	.82	.417	.01
$R^2 = .03$, F (3, 63) = .66, $p = .578$						
Predicted: HBQ Prosocial						
Verbal IC Composite	-.02	.06	-.05	-.37	.713	.01
KBIT IQ Standard	.01	.00	.39	2.76	.008	.06
Verbal IC x KBIT Interaction	.11	.06	.26	2.00	.050	.05
$R^2 = .12$, F (3, 64) = 2.99, $p = .037$						
Predicted: HBQ Overt Hostility						
Verbal IC Composite	-.02	.05	-.04	-.29	.772	.02
KBIT IQ Standard	.00	.00	-.20	-1.37	.176	.05
Verbal IC x KBIT Interaction	.05	.06	.11	.83	.413	.01
$R^2 = .08$, F (3, 64) = 1.81, $p = .154$						
Predicted: HBQ Relational Aggression						
Verbal IC Composite	-.09	.05	-.25	-1.86	.068	.17
KBIT IQ Standard	.00	.00	.02	-.16	.871	.00
Verbal IC x KBIT Interaction	-.02	.05	-.06	-.42	.674	.00
$R^2 = .07$, F (3, 63) = 1.54, $p = .214$						
Predicted: HBQ Asocial						
Verbal IC Composite	.05	.05	.14	1.07	.287	.03
KBIT IQ Standard	.00	.00	.03	.22	.827	.01
Verbal IC x KBIT Interaction	-.07	.05	-.17	-1.29	.202	.02
$R^2 = .06$, F (3, 64) = 1.42, $p = .244$						
Predicted: HBQ Social Inhibition						
Verbal IC Composite	.17	.08	.28	2.19	.032	.13

KBIT IQ Standard	.01	.01	.20	1.46	.148	.02
Verbal IC x KBIT Interaction	.03	.08	.04	.31	.755	.00
R^2 = .16, F (3, 64) = 3.90, p = .013						

Note. The interaction term describes unique variance in Prosocial activity.

Table 24

Results of Hierarchical Regression Analyses Determining a Potential Moderation Model with Verbal and Academic Variables

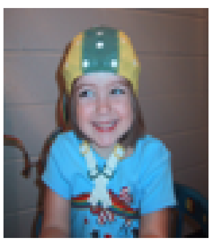
	B	SE(B)	β	*t*	*p*	sR^2
Predicted: HBQ Academic Competence						
Verbal IC Composite	1.05	.32	.69	3.32	.005	.50
KBIT IQ Standard	.00	.02	-.08	-.31	.760	.00
Verbal IC x KBIT Interaction	-.25	.34	-.18	-.74	.472	.02
$R^2 = .52$, F (3, 15) = 5.44, $p = .010$						
Predicted: WJ Emerging Literacy						
Verbal IC Composite	-.18	1.01	-.02	-.18	.862	.02
KBIT IQ Standard	.15	.06	.35	2.59	.012	.16
Verbal IC x KBIT Interaction	-.1.51	1.05	-.18	-1.44	.154	.02
$R^2 = .20$, F (3, 64) = 5.42, $p = .002$						
Predicted: WJ Math						
Verbal IC Composite	1.28	.50	.27	2.55	.013	.20
KBIT IQ Standard	.11	.03	.43	3.68	.000	.20
Verbal IC x KBIT Interaction	-.62	.53	-.13	-1.19	.241	.01
$R^2 = .41$, F (3, 64) = 14.81, $p < .001$						

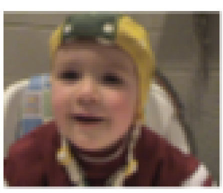
Note. The interaction term did not describe unique variance in any school readiness outcome.

Appendix A: Recruitment Materials

Recruitment Flyer Distributed to Families:

Cognition
Affect
Psychophysiology
LAB





The C.A.P Lab at Virginia Tech is currently conducting an Early Childhood Self-Regulation Study in **4 to 4.5 year old children**. We're interested in how children learn to control their actions during fun games, like Simon Says. We offer a **$10 Target gift card** as compensation for parents and a small toy for children, and **we can provide child care** for siblings. If interested please contact:

Amanda Watson
540-231-2320
watsonaj@vt.edu

VirginiaTech
Invent the Future

$10 Target Gift Card!

Child Care Available!

Department of Psychology
University Exemplary Department
IRB Project #13-440

Recruitment Letter Distributed to Local Community

Cognition Affect Psychophysiology LAB

June 5th, 2013

Dear Parent,

We hope this letter finds you and your family doing well! We are affiliated with the Psychology Department at Virginia Tech. This letter is to let you know that our latest *C.A.P. Study* is now focusing on children's developing ability to control their words and behaviors during games like Simon Says. We would love to invite you and your child to participate!

In our Early Childhood Self-Regulation Project, we would invite you and your child to visit us at the C.A.P. Lab while we play several different games with your child. Some of these games are fun "backwards games" in which we'll ask your child to give an unexpected response when he or she sees a card (such as saying "day" when he or she sees a card with a picture of a moon and stars). Other games involve your child correctly identifying and naming pictures. For all of these games, your child will be wearing a stretchy EEG cap so we can see what the brain is doing while your child is playing our games.

For this study, parents and their children will visit the C.A.P. Lab at Virginia Tech and will spend a total of 2 hours with us. Your child will be given a small gift as a "thank you" gift for participating in the study and you will be compensated with a $10 Target gift card for your participation. Our research lab is in Williams Hall (on the Virginia Tech campus). Williams Hall is located on the drill field next to Buruss Hall and we have reserved parking for participants in our research projects.

Would you be interested in hearing more about this study? Right now, we don't seem to have your telephone number on record. If you wish, feel free to call us at your convenience. We would love the chance to talk with you about our study. 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 would like to participate. In the meantime, feel free to visit the web site for our research lab. You can read about our lab and see photos of infants and children who have been involved in our studies.

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

If you wish to call us, we can be reached at ***(540)231-2320*** (research lab) and by e-mail (Ms. Watson's email address is *watsonaj@vt.edu)*. Thank you and we look forward to talking with you!

Sincerely,

Martha Ann Bell, Ph.D.
Professor of Psychology

Amanda Watson, M.S.
Graduate Student

Postcard Distributed in Mailings with Return Envelope

If you have a 4 to 4.5 year old and are interested in our study or are interested in being contacted about future research opportunities, please fill out the information below.

- I am interested in the current study
- I am interested in future research opportunities

Thanks for your interest!

Name:______________________ **Email:** ______________________
Phone number: _______________
Age of each child: _____________________________

Recruitment Email Distributed, with Permission, via Listservs

The C.A.P. Lab in the Psychology Department at Virginia Tech is conducting a new study focusing on children's developing ability to control their actions during games like Simon Says. During this visit, we will play some fun word and movement games. In addition to these games, we are interested in collecting information about the physiological components of these abilities.

The visit should last about 1-2 hours. We are looking for 4- to 4.5-year-old children. We offer a $10 Target gift card as compensation for parents and a small toy for children, and we can provide child care for siblings. If you are interested in this study, you may contact Amanda Watson by phone (research lab—*231-2320*) or by e-mail (*watsonaj@vt.edu*). (VT IRB: 13-440)

Telephone Protocol Used to Speak with Potentially-Interested Parents

Steps in recruiting children/parents for our research project:
1) initial research recruitment letters are mailed to parents during the month that the child will turn 4 years of age.
2) follow-up phone call is made to parent 1 to 2 weeks later to assess interest in participating
3) if parent is interested, an appointment is scheduled for child/parent to visit our research lab

Hi, this is Amanda Watson from the Psychology Department at Virginia Tech. We sent you a letter about a week ago regarding a study that we have going on in our research lab right now – the Early Childhood Self-Regulation Study. And I am just calling to see if you might be interested in participating.

Would you like to hear a little bit more about our research study?

We are currently looking at how young children learn to control their actions. We're specifically interested in this development in four-year-olds. We're interested in understanding more about children's developing abilities to control their words and their movements. If you are interested in participating, we would ask you both to visit us in our research lab and we would play some fun games with your child. You would be with your child during the entire visit to our research lab.

We also collect physiology measures in our lab. So, we collect heart rate measures and brainwave activity measures. This is so we can see what your child's brain and heart are doing during our games. These measures give us a little extra information about these skills and provide us with important information about the development of the brain. Our physiological measures are safe and are just like the ones they might use in the doctor's offices. The way we measure brain wave activity is with a little yellow cap – it is a stretchy cap, like a swim cap, with little sensors in it. Once we put the cap on, we put a couple of different gels into each sensor to help with the recording. We measure heart rate with two little sticky-patch sensors and we'll put these on your child's chest.

Once we get your child all geared-up, we will play a couple of games; some ask your child to move in a certain way (like tapping a pencil on a table twice when I tap it once) and some ask your child to say certain things (like saying "day" when shown a picture of a moon and stars). Then we'll play some other fun games to learn about your child's vocabulary and their school readiness.

The entire visit to our research lab will take approximately two hours, and we have a very flexible schedule and many times available. We want this to be fun for your child, so whatever time of day works best for you both is good for us.

Does this sound like something you might be interested in doing with your child?

Appendix B: Parental Permission Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Parent Consent Form

Title of Dissertation Project: Individual Difference in Inhibitory Control Skills at Four Years of Age

Researchers: Martha Ann Bell, PhD. and Amanda Watson, M.S.

I. Purpose of this Research

You and your child have been invited to be a part of a research study investigating how four-year-old children learn to control their action, like during a game of Simon Says. We're playing fun games with children, some of which are word games, and some of which are movement games. Specifically, we will examine how children's ability to control their movements differs from their ability to control their words by looking into how each of these skills relates to their school readiness, their vocabulary, and their temperament. We are also interested in examining how brain wave activity and heart rate are related to these specific skills during early childhood. What we learn from this study will help us better understand how these important skills develop in early childhood.

II. Procedures

A total of 68 children from the New River Valley area will contribute data to this investigation. This study involves a 2 hour visit to the C.A.P. LAB (Williams 348) at Virginia Tech. You will be asked to remain in the room with your child throughout the entire. This entire session will be videotaped. This study also involves three questionnaires (General Information Questionnaire, Health and Behavior Questionnaire, and Child Behavior Questionnaire). We have asked you to try to complete these brief forms at home prior to your child's visit to our research lab.

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

The first task is a vocabulary game, in which your child will be shown a picture and must correctly name the picture. Then we will play a series of brief Simon-Says-like games that are designed to be difficult for your child to correctly inhibit a response. For example, one game requires your child to say "day" when shown a picture of a nighttime scene and to say "night" when shown a picture of a daytime scene. In another game, your child will identify letters and numbers. Finally, your child will play one last word and picture game in which your child will, once again, be asked to correctly identify pictures.

III. Risks

There is minimal risk associated with this research project. The brainwave and heart rate procedures are similar to that done in a doctor's office and are not harmful. All brain-wave equipment is disinfected after each use. The heart rate equipment is disposable. If your child has an allergy to skin lotions, please inform us so that we can discuss the allergy and determine if any procedural changes need to be made. Our EEG gels are water based, but do not contain the same preservatives 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 has been made to encourage you and your child to participate in this study. In a scientific sense, however, this research study will give psychologists more information about the development of children's abilities to control their words and movements during early childhood.

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's name and code number will be kept in a file and locked in a file drawer. Only my professor Dr. Bell and I will have access to the 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 not be accessible to anyone else. Dr. Bell will supervise the confidentiality of the videotapes. Tapes will be erased 5 years after final publications of the results of this study.

If the Investigator (Dr. Bell) should ever become concerned that your child has a developmental delay, you will be told of the concerns. You will be given a list of referrals who will provide your family with a developmental screening of your child. If at any time during the study you request help in dealing with a child, Dr. Bell will provide referrals of both private and public agencies that offer assistance.

Also, if at any time there is a concern that your child is in danger due to abuse or neglect, the Investigator (Dr. Bell) will, after informing you, be obligated to contact the Department of Social Services and report the concern. This is in compliance with the mandatory reporting laws of the state of Virginia.

VI. Compensation

At the end of the session, your child will be given a small toy. Also, you will be compensated with a $10 Target gift card for your participation.

VII. Freedom to Withdraw

Your child may choose to stop playing the games at any time. You may also elect to withdraw your child from participation at any time without penalty. Your child will still be given the toys, and you will still be given the gift card.

VIII. 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

You will be asked to transport and accompany your child to the research laboratory for this visit. We also ask that you complete the questionnaires.

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 my child 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) Amanda Watson

Co-Investigator, Graduate student, 231-2320, watsonaj@vt.edu

2) Martha Ann Bell, Ph.D.
Principal Investigator, Professor of Psychology, 231-2546, mabell@vt.edu
3) David W. Harrison, Ph.D.
Chair, Psychology Department Human Subjects Committee, 231-4422, dwh@vt.edu
4) David Moore, Ph.D.
IRB Chair, 231-4991, moored@vt.edu

Photographer's Release (optional)
I understand that the photographs taken of my child are the property of Virginia Tech. These photographs will be used to illustrate Department of Psychology research at professional conferences, in professional publications, and/or in university/departmental literature (print and internet).

______________________________ ______________________
Parent's signature Date

Appendix C: Child Assent Form

Child Assent Form

Title of Dissertation Project: Individual Differences in Inhibitory Control Skills at Four Years of Age
Researchers: Martha Ann Bell, Ph.D., and Amanda Watson, M.S.

I. Explanation of Research to Child

We're going to play some fun games today. Some of the games are movement games and some are word games. For these games, you will get to wear our cool cap that looks like this. (Shows EEG cap to the child). At any time you can decide to stop playing these games. Just tell us, and we will stop.

II. Asking for Child's Verbal Assent

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

III. Witness Affirmation

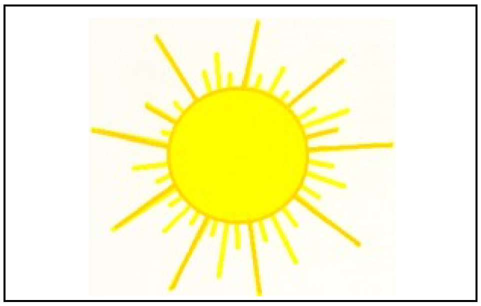
The child verbally agreed to participate in this research study. I understand that the parent will receive a copy of this assent form.

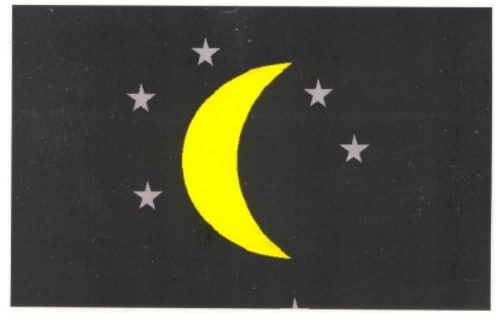
____
Child's name

______________________________ ____________________
Signature of witness Date

Appendix D: Stimulus Images Used in Day-Night and DCCS IC Tasks

Day-Night:





Silly Sounds Stroop: