Individual Differences in Executive Functions at Age Four: Adding Borders to the Day/Night Task

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Abstract (academic)

Inhibitory control is vital to typical development and matures rapidly throughout early childhood. Inhibitory control deficits are seen in both autism spectrum disorders and attention-deficit/hyperactivity disorder and, along with other executive functions, inhibitory control contributes to school success. The tasks used to measure and stress these skills in children have not been fully explored. Even given the cognitive development levels of young children, the current inhibitory control tasks for preschoolers are not completely comparable to the tasks used with adults. For my thesis study, I added a mixed condition to the day/night inhibitory control task in preschool children using methodological design features from the Dimensional Change Card Sort (DCCS) Task. This addition allowed the day/night task to serve as a better analogue to the Stroop task, which is an inhibitory control task commonly used with adults. In addition, electroencephalogram (EEG) illuminated the neural patterns of the task in children at age four. This study demonstrated that the borders condition of the day/night task is an appropriate executive function task that can be used with preschool aged children.

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Abstract (public)

Inhibitory control is the ability to keep from performing a dominant response and instead act in a different way. Inhibitory control deficits are seen in both autism spectrum disorders and attention-deficit/hyperactivity disorder and, along with other executive functions, inhibitory control contributes to school success. Although there a several tasks used in laboratories to measure this skill in children, they are not the same as the tasks used in adults. For my thesis study, I added a mixed condition to the day/night inhibitory control task in preschool children using methodological design features from the Dimensional Change Card Sort (DCCS) Task. In addition, electroencephalogram (EEG) showed the patterns of brain activation when four year old children complete this task. This study demonstrated that the borders condition of the day/night task is an appropriate executive function task that can be used with preschool aged children.

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Cognitive abilities develop throughout childhood. The measurement and prediction of these abilities, both behaviorally and neurologically, are of interest to this study. I will discuss the development of inhibitory control and behavioral tasks used to quantify inhibitory control in adults and children, as well as the ways that EEG can help illuminate these processes. I will then propose a third condition to the day/night task to improve its comparability to adult tasks and allow it to measure the spectrum of executive functions. I will also hypothesize the behavioral and neurological results of this modification before explaining the methodology and results. The findings and implications will then be discussed.

Executive Functions

Executive functions are a well-established way of describing the role that the frontal lobe plays in complex cognition, such as decision making and planning. Baddeley (1996) has postulated the existence of a theoretical central executive as part of his model of working memory. That is, in order for cognitive processes, such as working memory, to occur, there is a set of functions that must moderate those processes. Based on patients with frontal lobe damage and their apparent deficits with some types of complex cognitive tasks, but no deficits in IQ or less complex tasks, it is understood that the frontal cortex plays a vital role as the central executive.

Miyake et. al. (2000) used confirmatory factor analysis (CFA) to demonstrate that, within the broad term of executive function, it is possible to further separate at least three main functions that may be delineated from each other. The three functions discussed by Miyake and colleagues are updating, set-shifting, and inhibition. Updating is thought of as closely related to working memory and involves the monitoring of useful information and discarding of information that is no longer useful or related to the task at hand. Set-shifting is closely related to attention and is the ability to engage and disengage to the task at hand. Shifting involves not the motor movements of switching (e.g. changing eye gaze toward the newly relevant stimulus), but the cognitive ability to process a completely different task (e.g. a change in the rules of a game). Finally, inhibition, as previously defined, is the ability to override a dominant response to a stimulus and perform a less dominant response.

Although this tripartite model of executive functions is observable in adults, there is uncertainty when it emerges in children. Work with children in late childhood and early adolescence has replicated Miyake and colleagues' three-factor model. Lehto, Juujärvi, Kooistra, and Pulkkinen (2003) used similar methods in children from eight to thirteen and found that a three-factor model including updating/working memory, set-shifting, and inhibition, was the best fit for their data. Similar to Miyake and colleagues, the separate factors were correlated with one another, but were clearly separable in this age group.

Empirical evidence for clustering of factors in preschool children comes from Espy, Kaufmann, Glisky, & McDiarmid (2001) who administered executive functioning tasks (Tower of Hanoi, A-not-B, Spatial Reversal, and Shape School) to almost one-hundred preschool aged children. They found that their data did not load well onto a single model of executive functions and that tasks such as A-not-B, which is thought to measure inhibition, and Spatial Reversal, which is thought to measure set-shifting, loaded onto separate factors. This provides some evidence that executive functions might be differentiable into factors in preschool aged children.

However, more recent research from Wiebe and colleagues (2008), who performed a similar study to Miyake et al. (2001), but in children aged two to six years old, questions their previous two-factor solution. They used a variety of set-switching, working memory/updating, and inhibition tasks to test executive function in over two-hundred children. Controlling for maternal education and child's age, they ran a CFA to find the best and most parsimonious model that explained their data. They found that a unitary model, with a general factor of executive function, was the model that best accounted for their data. A three-factor model was not significantly better the single factor model for explaining their data. This work is helpful in attempting to replicate Miyake and colleague's methodology, but the limited repertoire and difficulty of designing executive function tasks in this age range must not be ignored. These findings could be due to task impurity, since tasks used in this age group are not as developed as for adults and are feasibly tapping into multiple factors of executive functioning, but more likely due to the small numbers of executive function tasks appropriate for early childhood. Despite this, inhibitory control has emerged as a quantifiable aspect of executive functions in early childhood.

Inhibitory Control

Inhibitory control is important for school readiness and is a vital precursor to self-regulation, which is the ability to respond to an emotional stimulus in a socially acceptable manner (Bierman, Torres, Domitrovich, Welsh, & Gest, 2009). Inhibitory control has been shown to predict performance in vocabulary, reading, and math fluency in elementary school (McClelland et al., 2007). In addition, lack of inhibitory control leads to impulsive decision making in adults (Logan, Schachar, & Tannock, 1997). There is some evidence that programs such as mindfulness training and exercise can improve inhibitory control in children (Diamond & Lee, 2011), which leads to the possibility of interventions to improve these skills. In order for interventions to occur, it is important that clinicians and experimenters are able to accurately assess inhibitory control.

One of the most common tests of inhibitory control for adults is the Stroop task. Dating back to the early 1900s, the Stroop evaluates the participant's ability to override the prepotent response of reading a word, rather than evaluating a color (Stroop, 1935). The first condition of the Stoop task asks the participant to report, either verbally or manually the color of a series of Xs. After several trials the next condition is introduced, asking the participant to report the color that is spelled out in black ink. This is followed by a condition in which the participant is still given the goal of reporting the color ink, but with an incongruent color word written (e.g. GREEN written in blue ink). The final, so called "mixed" condition asks the participant to report the color ink, unless the word is written in black ink, in which case they are to report the color written. The mixed condition is discussed in the literature as a measure of inhibitory control (Miyake et al., 2000), but obviously integrates elements of set-shifting and working memory in order to update the information from the stimuli and shift between the different rules. Response time for the incongruent trials is dramatically increased in typical population. Frontal lobe patients show increased difficulty with this task (Vendrell et al., 1995).

Deficits in inhibitory control are seen in disorders such as ADHD, schizophrenia, and autism. Adults with child-onset ADHD perform significantly worse on the Stroop task than IQ matched controls (King 2007). This finding holds, even when the ADHD group takes longer to respond, which usually increases accuracy. This deficit is seen in children diagnosed with ADHD as well, with those children showing less inhibitory control than children diagnosed with conduct disorder, although both are associated with impulsive behavior (Schachar, Tannock, &

Logan, 1993). Children with autism spectrum disorder show a similar pattern of reduced inhibitory control compared to controls (Christ, Holt, White, & Green, 2006).

Typically developing children also show a lack of inhibitory control early in development. Despite this, inhibitory control can be measured in infants through tasks such as A-not-B (Cuevas, Swingler, Bell, Marcovitch, & Calkins, 2012). This task involves researchers showing the infant a toy and hiding it under one of two buckets before diverting the infant's attention. The researcher then asks, "Where's the toy?" and records either the infant's look or reach toward the bucket (Bell & Adams, 1999; Diamond, 1991). Similarly, preschool executive function can be predicted in infants as young as five months by quantifying the amount of time that they spend looking at a novel stimulus. Research by Cuevas and Bell (2014) has shown that short lookers, infants with more efficient information processing skills (Colombo, Kapa, & Curtindale, 2010), develop better executive function skills in early childhood than long lookers.

With origins in infancy, executive functioning undergoes rapid improvement during early childhood. Specifically at age three, children have difficulty with tasks that require updating, shifting, and inhibition, but are fairly proficient at these tasks by five years (Carlson, 2005). This corresponds to frontal lobe development, which is slower than most other brain regions and undergoes rapid changes in synaptic density and grey matter pruning during this same period of early childhood (Diamond, 2002; Huttenlocher, 1979).

There are several Stroop-like tasks that are used to measure executive function in this age group. They include tasks such as snow/grass, yes/no, the hand game, and day/night (Carlson, 2005; Gerstadt, Hong, & Diamond, 1994; Simpson & Riggs, 2009). The day/night task has emerged as a popular measure for quantifying executive functioning in children. The straight version of the game requires the child to label the cards as they appear, with the sun card labeled "day" and the moon card labeled "night." Based on a study by Passler, Isaac, and Hynd (1985), the day/night Stroop task requires the child to say “day” in response to a picture of moon and stars and “night” in response to a picture of a sun. Similar to the adult version of the Stroop, this task requires the child to suppress the automatic response to a stimulus and report a less dominant response. Gerstadt, Hong, and Diamond (1994) reported that performance on this task rapidly increases from age three to five, with most five year olds being able to perform very well. The day/night task has been shown to predict reading and math achievement in elementary school (Monette, Bigras, & Guay, 2011).

Whether this task is a pure measure of inhibitory control has been debated in the literature. In the 1991 paper by Gerstadt, Hong, and Diamond, they present the task as requiring both working memory and inhibitory control. In later articles, however, a series of experiments provides evidence that the day/night task taxes only inhibitory control, not working memory. Diamond, Kirkham, and Amso (2002) had children aged four to four-and-a-half perform one of five variations of the day/night task. The first "dog/pig" condition had the children associate the labels dog and pig to the sun and moon cards. The second condition simplified the rules from two rules (say day when you see the moon and night when you see the sun) to one rule (say the opposite). The third version gave the children an interval before they were allowed to respond with their answer, during which the experimenter sang a little ditty. The fourth version the experimenter sang the same ditty, but between trials, so the child did not have to wait to respond to the stimulus. The fifth version was the same as the third, but card was flipped over so the child could not look at the card while the experimenter was singing the ditty.

The authors found that, contrary to the hypothesis that day/night required working memory, the children performed no better on the one rule version than the standard version. This provides evidence that inhibitory control, rather than working memory, is the primary demand of the task. Furthermore, adding the ditty in version three allowed the children to perform significantly better on the task at both four and four-and-a-half years. This effect was attenuated in the fifth condition, which added the memory component for four year olds but for four-and-a-half year olds. This can be interpreted as inhibitory control benefitting from increased time at age four, but not four-and-a-half. This finding is reconcilable with what is known about changes in executive functioning during this developmental period.

The proposed task

The Dimensional Change Card Sort (DCCS) is considered a measure of set shifting (Kloo, Perner, Aichhorn, & Schmidhuber, 2010). DCCS requires the participant to sort cards according to one dimension, such as color, before switching to sorting by another dimension, such as shape. After both of these conditions, the participant enters a mixed trial during which they sort by the color dimension if there is a black border around the card and by the shape dimension if there is no border. Children under four almost always fail the borders condition, while children older than four display a wide range of variability (Zelazo, 2006).

The borders version of DCCS presents a unique opportunity to add borders to the traditional day/night in order to create a mixed condition, analogous to the mixed condition of adult Stroop. This provides three conditions of the same task: day/night straight, day/night Stroop, and day/night borders. Each of these conditions probes different aspects of executive function. The straight condition requires simple sorting and can be thought of as a baseline condition, while the Stroop condition of day/night taxes inhibitory control, as shown by Diamond, Kirkham, and Amaso (2002). The borders condition acts as a broader measure of executive functions, with elements of working memory, set-shifting, and inhibitory control. By adding a borders condition to day/night, I can dissect the individual differences in executive functioning performance, using a single measure to assess individual differences in cognitive abilities in preschool aged children.

Neural Correlates of Inhibitory Control

Individual differences in executive functions are readily apparent in preschoolers. This variation can partially be explained by socio-economic factors and parental education (our data, unpublished), but is also accounted for by the rapid rate of neurological development during early childhood. Longitudinal work by Gogtay and colleagues (2004) obtained structural MRI scans at ages four and six for thirteen children. They found progressive pruning of grey matter over the frontal lobe between the two scans. This pruning of grey matter and changes in functional connectivity could be underlying differences in inhibitory control task performance.

Thatcher (1994) has used EEG to demonstrate similar age related changes in neurological function. EEG uses noninvasive scalp electrodes to measure changes in frequency and amplitude of electrical signals emitted from the brain. EEG has excellent temporal frequency and is able to record electrophysiological changes much faster than other methodologies. However, EEG has poor spatial resolution, so it is only possible to make statements about scalp electrode placement. Because it is noninvasive and provides compelling information about neural function, EEG is a preferred neuroimaging method to use with children and infants (Bell & Cuevas, 2012). EEG is observed in frequency bands, with different frequencies thought to relate to different cognitive functions. The band from 6-9 Hz has been established to be the dominant frequency band from infancy through early childhood (Bell, 1998; Marshall, Bar-Haim, & Fox, 2002). EEG power is a measure of EEG magnitude and reflects the excitation of groups of neurons. EEG coherence is a measure of functional connectivity and is thought to reflect white matter connections between areas and is calculated as the squared cross-correlation between two electrodes (Thatcher, 1994). If the areas of the brain are completely synchronized the coherence values will be near 1, whereas if the areas are not synchronized the value will approach zero.

EEG coherence has been linked with other executive functioning skills in adults, such as working memory. Sarnthein, Petsche, Rappelsberger, Shaw, and Stein (1998) found significant coherence between frontal and association cortices during a working memory task, compared to baseline. Synchrony between these brain areas provides evidence that executive functions rely not only on the frontal and prefrontal cortices, but also on associations across the brain.

Garavan, Ross, Murphy, Roche, and Stein (2002) used a go/no-go paradigm to measure inhibitory control while recording EEG Event Related Potentials (ERP) in adults. Unlike coherence, ERPs measure the average response of a single electrode to a repeated stimulus. The go/no-go task requires the participant to push a button in response to a stimulus (go) and refrain from pushing the button of response to a different stimulus (no-go). The way the task is set up a vast majority of the trials are "go" trials, leading to pushing the button becoming a prepotent response. The ability to suppress that now automatic response and refrain from pushing the button during a "no-go" trail is a measure of inhibitory control. Garavan and colleagues found a shorter latency of a P3 waveform at frontal and parietal electrodes when the participants successfully inhibited their response. This indicates that connectivity between frontal and parietal regions might account for the ability to suppress a prepotent response.

Cuevas, Hubble, and Bell (2012) reported that task related changes in EEG power at medial frontal electrodes measured pre-kindergarten added significant unique variance to a model statistically predicting executive functioning in post-kindergarten aged children. Similarly, Wolfe and Bell (2007) measured working memory and IC (including the day/night task) in three-and-a-half to four-and-a-half year olds while recording EEG. They found a main effect for task condition, with four and four-and-a-half year olds having significantly more power at frontal and medial frontal electrodes during task than at baseline. It is possible that EEG power in frontal electrodes may show not only differences based on task condition, but could show performance differences on the task.

Watson (2014) had four-year-old children perform a battery of verbal and motor inhibitory control tasks while collecting EEG data. She found that performance on the yes/no task was statistically predicted by lateral frontal baseline and task EEG. Similarly, lateral frontal EEG at baseline, but not at task predicted performance on the hand game. Both of these games are Stroop-like and measure inhibitory control.

In preschool children, work by Bell and Wolfe (2007) has shown increased coherence between frontal and medial temporal areas during the day/night task, compared to baseline. Although frontal associations are important for inhibitory control, it has not yet been shown that coherence between frontal areas can predict performance on the day/night task.

The current study uses recordings of power and coherence to statistically predict individual differences in performance on the modified borders version of the day/night task in preschool aged children.

Hypotheses

Performance on borders condition. The borders condition of the day/night task will be more difficult than the Stroop and straight conditions of the task. Age and verbal IQ will correlate with performance, so that older children and those with higher IQ will perform better on the borders condition of the task. The inhibitory control dimension of the CBQ and score on the global executive composite index summary on the BRIEF-P will be correlated with performance on each of the three day/night conditions.

Behavioral predictors of performance. The hand game and yes/no task will significantly predict performance on all three conditions of the day/night task.

Working memory and set-shifting will be stronger predictors and account for more variance for day/night borders performance than they do for the Stroop and straight conditions.

Neural predictors of performance. High and low performers on day/night borders will demonstrate different EEG patterns during task. Frontal EEG (F3, F4, F7, F8) power in the 6-9 Hz band during task and baseline will predict performance on day/night borders. Coherence in the 6-9 Hz band between frontal (F4-F8 and F3-F7) regions during task and baseline will predict performance on day/night borders.

In addition, a model including all verbal IQ, age in months, and all EEG predictors will explain significant variance in performance on the day/night borders condition.

Method

Forty-three children were recruited from the New River Valley and surrounding areas using existing data bases and flyers in areas populated by young families, including parks, recreation centers, and daycare facilities. A G*power analysis showed that a sample size of 39 participants (f^2=.6, predictors=7) was necessary based on a similar study from the Cognition, Affect, and Psychophysiology (C.A.P.) lab predicting working memory performance in preschool aged children (Watson, 2014). Children were between 48 and 59 months at the time of appointment, based on evidence that executive functions stabilize by four years (Alloway, Gathercole, & Pickering, 2006), with no history of medical or psychological disorders. Two children were excluded from all analyses, one because he was over 60 months of age and the other because he was diagnosed with Sensory Processing Disorder, bringing the sample size down to 41. The average age of children included in the study was 4.46 (SD 0.30), while the average age for mothers was 32.83 (SD 4.55) and for fathers was 32.37 (SD 5.05). As far as education, 75.6% of mothers and 73.2% of fathers had completed a college degree of higher, with 6 sets of parents not reporting education. In terms of ethnicity, 7.3% identified as Hispanic, 78% identified as non-Hispanic, and 14.6% did not report ethnicity. In terms of race, 4.9% of children were reported as being Asian, 2.4% as being Black or African American, 9.8% as Other/Multiracial, 82.9% as being White.

Parent's time was compensated with a $10 gift card and the children were allowed to choose a toy worth approximately $10 to take home. Interested participants were screened through phone or email to ensure eligibility before an appointment was scheduled. Questionnaires and consent forms were sent to the parent in advance of the appointment.

Participants arrived at Williams Hall on Virginia Teach campus with a parent or guardian. They were greeted and given a parking pass before being escorted to the C.A.P. lab. A brief verbal outline of the schedule was given and the parent was asked to sign a written consent form. Verbal assent was obtained from the child and witnessed by both the parent and another lab member.

The questionnaires that had been previously mailed to the parents were then collected. If the parent had forgotten or there had not been time prior to the appointment they were requested to fill them out during the appointment. The questionnaires collected were Child Behavioral Questionnaire, Behavioral Rating Inventory of Executive Functions, and a general information questionnaire that asked the child's birth date and other demographic information.

The EEG electrodes were applied while the child completed the Peabody Picture Vocabulary Test (a verbal assessment of IQ) with a research assistant. Children were capped following lab protocol using a 32 electrode cap. Electrode impedances were accepted if they were under 5K ohms. Electrical activity form each lead was amplified using a James Long Bioamps. The signal was sampled at 512 samples per a second. Editing for excessive movement artifacts was done using simultaneously collected electrooculogram to control for eye movements. EEG power was analyzed at the 6-9 Hz frequency band. EEG data was analyzed using EEG Analysis System software from the James Long Company. Coherence between *a priori* hypothesized electrodes was calculated in the 6-9 Hz band. EEG was collected during the remainder of the appointment.

Baseline EEG was recorded for two minutes while the child watched a brief clip from Disney's Finding Nemo that consisted of sea turtles riding the East Australian current.

Inhibitory control tasks

The inhibitory control tasks began with a teaching session during which children were taught the rules of the task and given an opportunity to demonstrate understanding by practicing these rules. In order to respond correctly during each trial, children needed to withhold a dominant response in order to produce a subdominant response, requirements which are hallmarks of inhibitory performance.

The day/night, yes/no, and fishes and sharks are all inhibitory control tasks, requiring children to demonstrate inhibition of prepotent responses. Yes/no required children to respond with a "yes" or "no" in response to experimenter shaking their head and nodding their head, respectively. There were twelve trials and the variable of interest was the total proportion correct, with a half point given when the child self-corrected. Interrater reliability was calculated for 20% of the sample and the resulting Intraclass Correlation Coefficient (ICC) was 0.99 for the yes/no task.

The fishes and sharks game is a go/no-go paradigm when the children are taught to push the space bar to catch the fish and not press the space bar when shown a shark (Wiebe, Sheffield, & Espy, 2012). This task began with three practice sessions, one during which the child pushed the space bar for three fish, then one practice session which the child refrained from pushing the spcae bar for three sharks, and then finally a mixed practice where the child was shown four fish and two sharks in random order and had to achieve 75% accuracy in order to continue to the test condition. If the child did not pass they were allowed to go through the practice again. The task contisted of 40 trials (30 fish and 10 sharks) in pseudorandom order so the child was presented with one shark for every three fish. A sensitivity index d' was calculated as the variable of interest by setting the mininum number of false alrms hits as one and then subtracting the z-score of false alarms from the z-score of hit rate (Macmillan & Kaplan, 1985).

The novel aspect of this study is the use of the day/night borders condition. First the child completed the straight version of the day/night game simply labelling the sun card "day" and the moon card "night. They then progressed to the traditional version of day/night which requires children to say “day” in response to a picture of moon and stars and “night” in response to a picture of a sun. After twelve trials, the child moved to a borders condition of day/night where they were instructed to label the moon card as "day" when the card has a red border and as "night" when there is no border. They were then told that they should lable the sun card as “night” when there was a red border and as “day” when there was not a border (Figure 1). The rule, “borders is the silly way, not border is the regular way,” was repeated before every trial, as is done in DCCS. The variable of interest was the total proportion correct, with half a point being given if the child self-corrected an incorrect answer. Reliability was calculated for 20% of the sample and the ICC was 0.98 for the straight condition, 0.96 for the Stroop condition, and 1.00 for the borders condition.

Other executive function tasks

The children also completed the Dimension Change Card Sort Task which began with the child being taught the rules of the game and given two practice cards to sort. The child then sorted the cards according to one dimension (e.g. shape) for six trials before being instructed to switch to the other dimension (e.g. color) for six more trials. This was followed by twelve trials where the child sorted according to one dimension if the card had a black border around the edge and the other dimension if the card did not have a border. This is considered a measurement of set-shifting. The variable of interest was the total proportion of cards sorted correctly during the borders condition of the task. Realiability was calaculated for 20% of the sample and the resulting ICC was 0.99.

A working memory task was administered that required the child to remember a list of objects and sort them in size order with number of objects in the list progressively increasing (Tulsky et al., 2013). This allowed me to measure how well the child could manipulate information in the short term. List sorting task was administered via the NIH Toolbox at www.assessmentcenter.com. The variable of interest was score on the list sorting task, which was calculated by giving two points for getting the first question correct and one point for every correct answer after that (Tulsky et al., 2013). Interrater reliability was calculated for 20% of the sample and the ICC was 1.00.

The above tasks were counterbalanced across participants, with the exception of the entirety of the day/night task, which was always administered first. The entire protocol for each laboratory visit lasted approximately 60 minutes. After the final task, the EEG cap was gently removed and the gels were washed from the child's hair while the child chose their toy to take home.

Results

Data analysis began by examining the distributions of the variables for outliers and calculating correlations between the variables of interest (Tables 1 and 2). Outliers with scores more than three standard deviations from the mean were investigated to ensure that they were accurate representations of the child's performance and then included in the analyses. There were three outliers more than three standard deviations below the mean on the straight condition of the day/night task, two on the Stroop condition, and two on the borders condition. Because the distribution of DCCS was highly leptokurtic (kurtosis= 2.89, SD= 0.80), there were a total of eight outliers, four above and four below three standard deviations from the mean. The yes/no game had three outliers more than three standard deviations below the mean, but the list sorting and fishes and sharks tasks did not have any outliers.

One child was removed from the Stroop and borders versions of the day/night task because, although he passed the pretest, during the test trials he answered two questions correctly and then gave all incorrect answers while laughing, giving the impression that the errors were on purpose. Another child had straight and Stroop trials removed because of experimenter error. Two children did not receive the list sorting task because it had not yet been added to the protocol during their visit and one child refused to complete yes/no. Finally, three children did not pass the DCCS post-switch condition, and therefore did not progress to the DCCS borders condition.

Performance on Borders Condition

Performance on the borders condition of the task was not significantly different than the Stroop version of the task, $t = -1.14$, $p > .05$, and children performed significantly worse on both the Stroop, $t = 3.45$, $p < .01$, and borders, $t = 2.83$, $p < .01$, conditions than the straight condition. There was no difference in performance by gender, $F(38) = .66$, $t = -1.33$, $p > .05$, nor was performance significantly correlated with age in days (Table 1). Age in days was not included as a control in any of the analyses, because it was not associated with any of the measures (Table 2).

As shown in Table 1, the borders version of the task was not significantly correlated with the inhibition subscale, inhibitory self-control index, or global executive composite on the BRIEF-P or the inhibitory control or effortful control scales in the CBQ. The Stroop version of the task was negatively correlated with all three measures of interest in the BRIEF-P. Because the BRIEF-P is a clinical index, a higher score signifies more impairment, meaning that a lower score signifies better inhibition and executive function. The hypothesis that BRIEF-P scores were related to the Stroop version was supported, but the hypothesis that BRIEF-P would be related to the borders version was not supported.

Behavioral Predictors of Performance

I hypothesized that the fish and sharks and yes/no task would significantly predict performance on all three conditions of the day/night task. Yes/no was significantly correlated with straight and borders conditions of the day/night task. A regression model with the yes/no task and PPVT accounted for significant variance on day/night borders $F(2, 36) = 5.10$, $p < .01$, and day/night straight, $F(2, 36) = 5.25$, $p < .01$, but not the Stroop, $F(2, 36) = 1.79$, $p > .05$, condition of the task. The fish and sharks task and PPVT significantly predicted both the straight,

F (2, 37) = 8.39, p < .01, and Stroop, F (2, 37) = 5.19, p < .01, versions of the task. While the fish and shark task was not significantly correlated with performance on the borders condition (although it was approaching significance with a p of .09) the regression analysis including PPVT and predicted significant variance, F (2,37) = 3.78, p < .05 (Table 3).

The list sorting task and DCCS performance was not significantly related to performance on any of the three conditions of the day/night task. The hypothesis that working memory and set-shifting would be more related to the borders version of the task than the other to conditions was not supported.

Neural Predictors of Performance

To test the hypothesis that frontal EEG (F3, F4, F7, F8) power during task and baseline would predict performance on day/night borders I ran a multiple regression analysis with change of power between baseline and task for each electrode pair (F3/F4 and F7/F8) to the model predicting percentage correct on day/night borders, while controlling for receptive language (PPVT). This regression was not significant for F3 and F4, F (2,36) = 1.83, p >.05. Nor was it significant for F7 and F8, F (2, 36) = 1.81, p > .05. The hypothesis that baseline and task power would predict task performance was not supported.

To test the hypothesis that coherence between frontal (F4-F8 and F3-F7) regions during task and baseline would predict performance on day/night borders I ran a similar regression model with change in coherence between baseline and task for electrode pairs F4-F8 and F3-F7 predicting percentage correct on day/night borders, while controlling for PPVT. This model was not significant, F (3,36) = 2.51, $p > .05$. The hypothesis that baseline and task coherence would predict task performance was not supported.

Post-Hoc Analyses

After testing the original hypotheses, it became clear that the EEG analyses were not addressing the principle question of if and how the day/night borders condition is different from the traditional version of the task. Thus, I conducted a series of analyses to determine if the neural patterns of children performing the borders condition were different from when they were performing the other versions of the day/night task. I chose to examine each of the hypothesized power and coherence pairs.

To test this hypothesis, I ran a 3 (condition) x 2 (F3 and F4 EEG power during task) repeated measures MANOVA. This MANOVA showed no effect for condition and hemisphere, nor an interaction between the two (Figure 2). In addition, I ran a 3 (condition) x 2 (F7 and F8 EEG power during task) repeated measures MANOVA. There was a significant main effect for condition, $F(2, 37) = 4.27$, $p < .05$, and no effect by hemisphere or interactions between the two (Figure 3). Based on the original hypothesis that frontal coherence would also be related to day/night borders, I ran a third 3 (condition) x 2 (F3-F7 and F4-F8 EEG coherence during task) repeated measures ANOVA. This model produced a significant effect for condition, $F(2, 37) = 13.29$, $p < .01$ and for hemisphere, $F(1, 38) = 15.68$, $p < .01$, but no interaction between the two (Figure 4).

To further understand the behavioral performance on the day/night borders task I plotted the correlation between performance on the borders and Stroop variations of the task and superimposed 75% cutoffs to indicate passing (Figure 5). Eight children passed the borders condition but did not pass the Stroop condition, whereas three passed the Stroop condition, but did not pass the borders condition. Four children failed both conditions and the remainder (twenty-four) passed both the Stroop and borders conditions.

Discussion

The addition of a unique borders condition to the traditional day/night ask yielded an interesting pattern of results that, while not entirely consistent with my hypotheses, provide insight into the abilities and structure of executive functions in four-year-old children. Performance on the borders condition of day/night was not significantly correlated with parental report of inhibitory control or executive functions as measured by the BRIEF-P, although the correlations did trend in the same direction as the significant correlations between the Stroop condition and BRIEF-P components. This demonstrates that the borders condition may not exclusively be associated with inhibitory control, but most likely does require some aspect of inhibition.

The inhibitory control and effortful control subscales of CBQ were not correlated with any of the day/night conditions. This is most likely because the CBQ measures temperamental inhibition, which, although related to cognitive inhibitory control, is more closely tied to self-regulatory capacity and behavioral inhibition (Diamond, 2013; Rothbart, Ahadi, Hershey, & Fisher, 2001). The CBQ may not have been the most appropriate choice to examine the cognitive inhibition required for the day/night task.

Although the correlations between the three conditions of the day/night game were not significant, this might be due to the limited sample size. The correlations between the borders condition and the straight and Stroop conditions were .21 and .20 respectively. It is possible that these correlations might have been significant if the sample had been larger, as the correlations were in the hypothesized direction, but did not meet the cut off for significance. The borders condition was not correlated with any of the other cognitive tasks, with the exception of yes/no. It is counterintuitive that the straight and borders, but not Stroop, condition of day/night was correlated with the yes/no game. The correlation was in the same direction, but also did not reach significance. Because previous work has collapsed the day/night and yes/no tasks together as a composite of inhibitory control (Wolfe & Bell, 2004), it seems likely that the lack of significant association between the yes/no and Stroop condition of the day/night task is due to the current study being underpowered and, had more children participated, there most likely would have been a significant correlation between the two tasks. Although the sample size was decided based on a G*power analysis, the sample recruited by Watson (2013) may not have been representative of the population in the rural college town where both samples were collected. In addition, because of the novel protocol employed in this study, it was difficult to estimate the power needed.

Interestingly, none of the day/night conditions were associated with performance on our working memory task. This fits in with the findings by Diamond and collegues (2002) that reducing the working memory does not make the task easier for preschool aged children. In addition, I purposefully followed the lead from DCCS and reduced the working memory component for the borders condition of the task by repeating the rules, "border is the silly way, no border is the regular way," before every trial. Although I hypothesized that working memory would be associated with the borders condition, it may be that at age four working memory and inhibitory control are already separated enough to functionally differentiate and therefore not correlate with each other. Espy and Bull (2005) found no differences in performance on inhibitory control performance between children with a digit span of three and those with a digit span of five. This suggests that by age four, many children do not demonstrate an association between inhibition and working memory, further supported by the lack of correlations seen here between measures of inhibitory control and working memory.

The DCCS borders condition was not associated with any of the executive functioning tasks, nor with PPVT or age. Although it is surprising that a well-regarded and widely used task was not correlated with any of the other measures, this can be explained by how poorly most children performed on the task (mean= .53) and how little variance there was in proportion correct. This is despite the inclusion of DCCS in the NIH toolbox Early Childhood Cognition Battery, which is validated for ages three through six (Zelazo et al., 2013). Much of the work using DCCS in children three and four years of age uses the pre-switch or post-switch conditions as the variable of interest, rather than the borders condition (e.g. Perner & Lang, 2002; Wolfe & Bell, 2007). The success of children in this study on the borders condition of the day/night task, using a similar protocol to DCCS, might indicate that borders day/night is a more age-appropriate measure of set shifting and executive function than DCCS at this age.

The reason why children performed substantially better on the day/night borders condition compared to the DCCS borders condition remains open. Previous work has shown that children perform better on the Stroop condition of the day/night task when they are asked to pair day and night to abstract designs, compared to when they are asked to pair day with the moon card and night with the sun card (Gerstadt et al., 1994). Further work by Diamond and collegues (2002) has shown that four year old children perform better on the day/night task when instructed to say "dog" to one of the traditional moon/sun cards and "pig" to the other card. This suggests that the children were able to execute the two rules better when there was not a conceptual tie between the label and the image on the card. However, in the current study, children performed better on the conceptually tied day/night borders condition than the randomly assigned DCCS borders condition during which they had to arbitrarily associate features with borders.

Work on DCCS has shown that children's difficulty with the task might result from inability to switch salient features. If the salient feature of color was the background of the card, children performed significantly better on the task as a whole (Diamond, Carlson, & Beck, 2005). This evidence, along with work from Kloo and Perner (2005), suggests that during DCCS, children perform better if the salient features are separated, rather than integrated into each other.

Despite this, children performed better on the day/night borders version of the task that used conceptually similar constructs than DCCS borders, which uses unrelated constructs of shape and color. One reason for this may be the ability for four-year old children to collapse the two rules of the game into one "say the opposite" rule. Although the experimenter never suggested or mentioned that the "silly way" was analogous to opposite, there is evidence that four-year old children understand the concept of "opposites" and may be able to employ the construct independently. Phillips and Pexman (2015) showed that children at age four are able to sort images by opposites when instructed by an experimenter, but children at age three did not perform above chance. In another study, Morris (2003) found that four and five year old children could spontaneously create opposite terms and, although they had difficulty explaining their approach, were able use opposites in regard to picture creation without being prompted to do so.

Given the ability of four-year olds to potentially understand implicit suggestions of opposites, the disparity between performance on the day/night and DCCS borders conditions might be due to the spontaneous collapsing of the rules in the day/night task and understanding the implicit directions to merely say the opposite. The same similarities between the constructs of day and night that make the Stroop version of the task more difficult for children than simple sorting, might also be the feature that makes the borders condition of day/night more accessible than the borders condition of DCCS. Further work will have to be done to inform this possibility, including perhaps a qualitative follow up question to the children after completing the day/night borders condition as to what their strategy was.

In terms of the neurological predictors of executive function, the hypothesized regression analyses were not significant. This is contrary to previous work which has found that EEG change from baseline to task is a predictor of inhibitory control in preschoolers (Bell & Wolfe, 2007; Swingler, Willoughby, & Calkins, 2011; Wolfe & Bell, 2004). Although this is surprising based on previous work which found that lateral frontal EEG is predictive of similar Stroop like tasks (Watson, 2014), there was a deviation from the traditional version of this task, and perhaps different pairs of electrodes would be more appropriate for examining a task that requires different cognitive processes than the traditional day/night task. Future directions may include looking at parietal and temporal activity and its relation to performance on the borders condition of the day/night task.

In hindsight, the proposed regression analyses did not accurately reflect the question of how the day/night borders condition is processed in the brain, thus leading to the post-hoc analyses. The significant effects of condition were seen in the F7 and F8 power and F3-F7 and F4-F8 coherence analyses for the three versions of the day/night task, but not for the F3 and F4 power analysis. The repeated measures MANOVA task F7 and F8 power analysis showed a bilateral step-wise increase in power from the straight to Stroop to borders condition. This suggests that the lateral frontal areas of cortex were significantly more active as the task progressed.

On the contrary, coherence between ipsilateral frontal areas decreased as the task progressed. The decrease in coherence signifies that the cortical areas are working independently of each other. Similar patterns have been found in adults, with fronto-frontal coherence decreasing as working memory-load increases beyond capacity (Zhang, Zhao, Bai, & Tian, 2016). In addition, work by Swingler and collegues (2011) found in preschoolers, of the electrodes that showed a change, coherence decreased from baseline to task. This suggests that in young children an increase in cognitive load is associated with a decrease in EEG coherence.

In addition, there was also a main effect for hemisphere in all three conditions of the day/night task, with higher coherence between right frontal compared to left frontal electrodes. This same effect was seen in comparing baseline coherence (t = -3.63, $p < .01$) and most likely represents a trait of the sample (Fox, 1991)

The main effects for condition appeared despite the lack of differences in performance between the Stroop and borders condition. These neurological differences suggest that the children may have had to work harder during the borders condition than the Stroop condition. It seems possible that there may have been behavioral differences if there was not a ceiling effect for each condition of the day/night task. Perhaps in younger children or a sample with less parental education there might have been significant differences in performance on the Stroop and borders conditions.

The relationship between the Stroop and borders conditions of the day/night task was not as robust as predicted. Some of this can be attributed to lack of variance, as the mean of performance on both tasks was high. In addition, there were some children who performed well on the Stroop version of the task, but performed poorly on the borders condition. These children's results supported the hypothesis that the Stroop condition was easier than the borders condition. However, there were eight children who failed the Stroop condition, but passed the borders condition. There is the possibility that these children did not fully understand the rules of the game during most of the Stroop condition and with the added practice were able to understand the rules of the borders condition better than they might have if the conditions were altered. Unfortunately, this is a difficult hypothesis to test, because, like the adult Stroop and DCCS, the conditions naturally build on each other.

Future directions of this line of research involve recoding the EEG recordings and separating the EEG power and coherence of trials that children got correct versus trials which they got incorrect. Rather than predicting children's overall performance, perhaps the cortical activity during a trial can predict if the child will answer correctly or incorrectly.

Adding the borders condition to the day/night task not only makes it more analogous to the adult Stroop, but also provides a potential alternative to DCCS in younger children. It remains to be seen if three and three-and-a-half year old children or children from a more diverse background than the highly educated, primarily Caucasian sample available in Blacksburg, VA are able to comprehend and complete the task.

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Table 1. *Questionnaire correlations with performance on three versions of the day/night task.*

Variable	BRIEF- IC	BRIEF- ISCI	BRIEF-GEC	CBQ-IC	CBQ-EC
DN Straight	.02	.09	.09	-.07	.04
DN Stroop	-.40*	-.37*	-.33*	.26	.18
DN Borders	-.13	-.09	-.14	.23	.12
Mean (SD)	64.68 (23.80)	69.15 (25.76)	64.59 (24.45)	4.84 (0.85)	5.40 (0.60)

Note. BRIEF-IS: BRIEF-P Inhibition Scale; BRIEF-ISCI: BRIEF-P Inhibitory Self-Control Index; BRIEF-GEC: BRIEF-P Global Executive Composite; CBQ-IC: CBQ- Inhibitory Control Dimension; CBQ-EC: CBQ Effortful Control Composite.
N= 41.
*p<.05. **p<.01.

Table 2. *Correlations between cognitive tasks.*

Variable	1.	2.	3.	4.	5.	6.	7.	8.	Mean (SD)	N
1. DN Straight	-								0.93 (0.09)	40
2. DN Stroop	.09								0.79 (0.26)	39
3. DN Borders	.21	.20							0.84 (0.20)	40
4. DCCS	.13	-.21	.09						0.53 (0.19)	37
5. Yes/no	.35*	.18	.39*	.19					0.76 (0.27)	40
6. Fishes and sharks	.48**	-.35*	.27	.10	.18				1.93 (0.56)	41
7. List sorting	.13	.06	.03	.08	.13	.11			2.69 (1.45)	39
8. PPVT	.39*	.27	.34*	.01	.19	.24	.43**		114.05 (12.30)	41
9. Age in days	.03	-.23	-.07	-.30	-.07	.00	.11	-.01	1627.37 (109.85)	41

Note. *p<.05. **p<.01.

Table 3. *Summary of regression analyses using behavioral tasks to predict performance on each of the day/night conditions.*

Outcome		B	SE	β	t	*p*
DN Straight						
	Fishes and Sharks	.07	0.02	.41	2.92	.01
	PPVT	.00	0.00	.29	2.08	.05
	Summary	R^2=.31		F=8.39**		
DN Stroop						
	Fishes and Sharks	-.20	0.08	-.39	-2.65	.01
	PPVT	.01	0.00	.32	2.14	.04
	Summary	R^2=.22		F=5.19**		
DN Borders						
	Fishes and Sharks	.10	0.06	.24	1.57	.13
	PPVT	.01	0.00	.31	2.07	.05
	Summary	R^2=.17		F=3.78*		
DN Straight						
	Yes/no	.09	0.05	.29	1.91	.06
	PPVT	.00	0.00	.33	2.20	.03
	Summary	R^2= .23		F=5.25**		
DN Stroop						
	Yes/no	.12	0.15	.13	.79	.43
	PPVT	.01	0.00	.25	1.51	.14
	Summary	R^2=.09		F=1.79		
DN Borders						
	Yes/no	.01	0.00	.27	1.76	.09
	PPVT	.25	0.11	.34	2.23	.03
	Summary	R^2=.22		F=5.10**		

Note. *p<.05. **p<.01.

Table 4. *Summary of regression analyses using EEG change to predict performance on the borders condition of the day/night task.*

Outcome		B	SE	β	t	*p*
DN Borders						
	Task-baseline power F3	-.14	0.20	-.19	-0.67	.51
	Task-baseline power F4	.06	0.21	.07	0.26	.80
	PPVT	.01	0.00	.33	2.12	.04
	Summary	R^2=.13		F=1.83		
DN Borders						
	Task-baseline power F7	.13	0.22	.15	0.60	.55
	Task-baseline power F8	-.17	0.20	-.21	-0.82	.42
	PPVT	.01	0.00	.34	2.20	.04
	Summary	R^2=.13		F=1.81		
DN Borders						
	Task-baseline coherence F3-F7	.08	0.50	.02	0.16	.88
	Task-baseline coherence F8-F4	-.76	0.48	-.24	-1.60	.12
	PPVT	.01	0.00	.37	2.38	.02
	Summary	R^2= .17		F=2.51		

Table 5. *Descriptive statistics for EEG.*

EEG Variable	Mean (SD)	N
Task-baseline F3	-0.05 (0.28)	40
Task-baseline F4	-0.03 (0.27)	40
Task-baseline F7	-0.01 (0.23)	40
Task-baseline F8	0.01 (0.25)	40
Task-baseline F3-F7	-0.04 (0.06)	40
Task-baseline F4-F8	-0.02 (0.07)	40
DN Straight F7	3.20 (0.38)	39
DN Straight F8	3.22 (0.39)	39
DN Stroop F7	3.23 (0.39)	39
DN Stroop F8	3.25 (0.40)	39
DN Borders F7	3.28 (0.42)	39
DN Borders F8	3.30 (0.41)	39
DN Straight F7-F3	0.52 (0.08)	39
DN Straight F8-F4	0.57 (0.12)	39
DN Stroop F7-F3	0.49 (0.09)	39
DN Stroop F8-F4	0.56 (0.09)	39
DN Borders F7-F3	0.47 (0.08)	39
DN Borders F8-F4	0.53 (0.10)	39

Table 6. *Main effects and interactions of task EEG.*

Task		F	*p*
DN Power F4 and F8			
	Condition	0.53	.59
	Hemisphere	0.285	.60
	Condition x hemisphere	1.42	.26
DN Power F7 and F8			
	Condition	4.27	.02
	Hemisphere	0.81	.37
	Condition x hemisphere	0.06	.94
DN Coherence F3-F7 and F4-F8			
	Condition	13.29	.00
	Hemisphere	15.68	.00
	Condition x hemisphere	0.63	.54

Figure 1. *Day/night stimuli without borders (left) and with borders (right).*

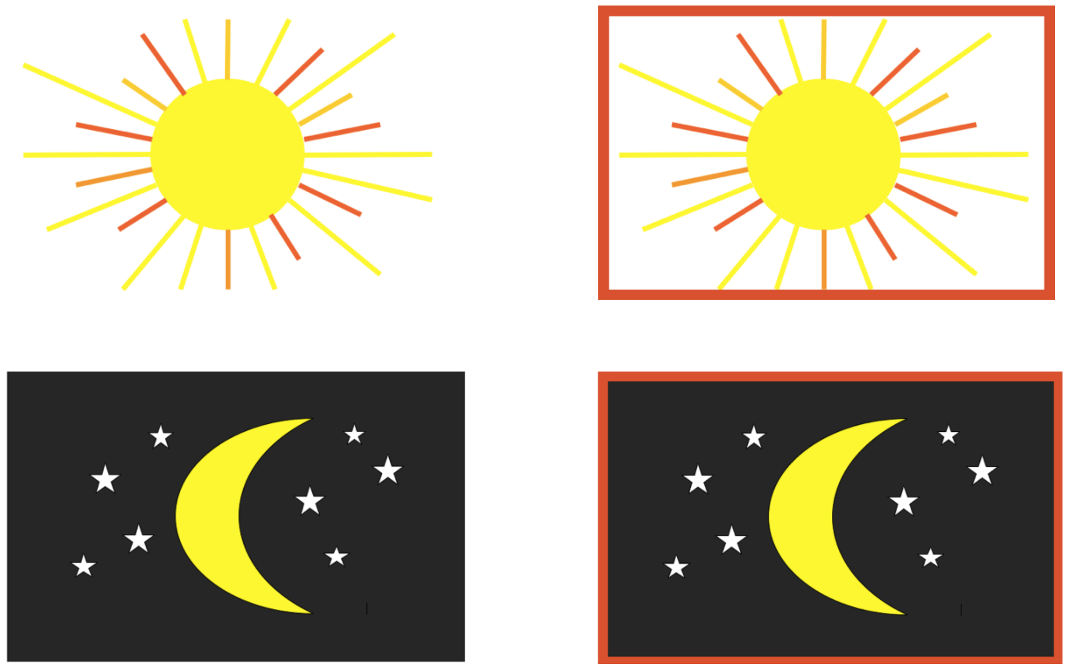


Figure 2. *Repeated measures MANOVA comparing medial frontal EEG power during day/night task.*

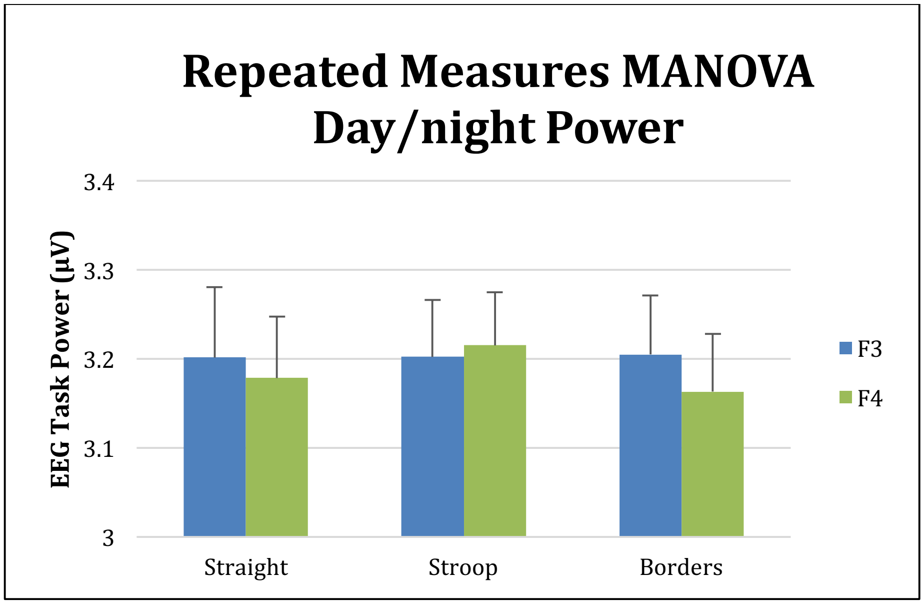
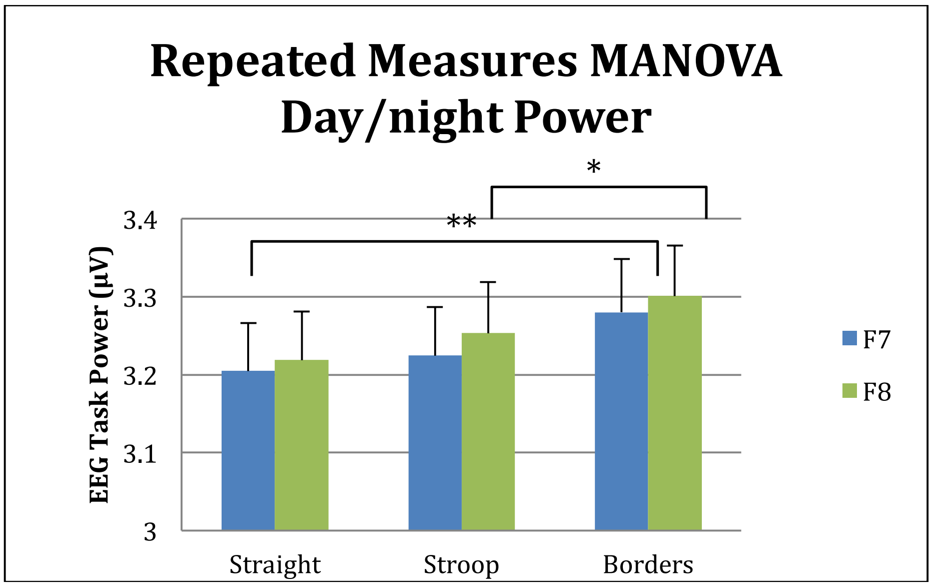


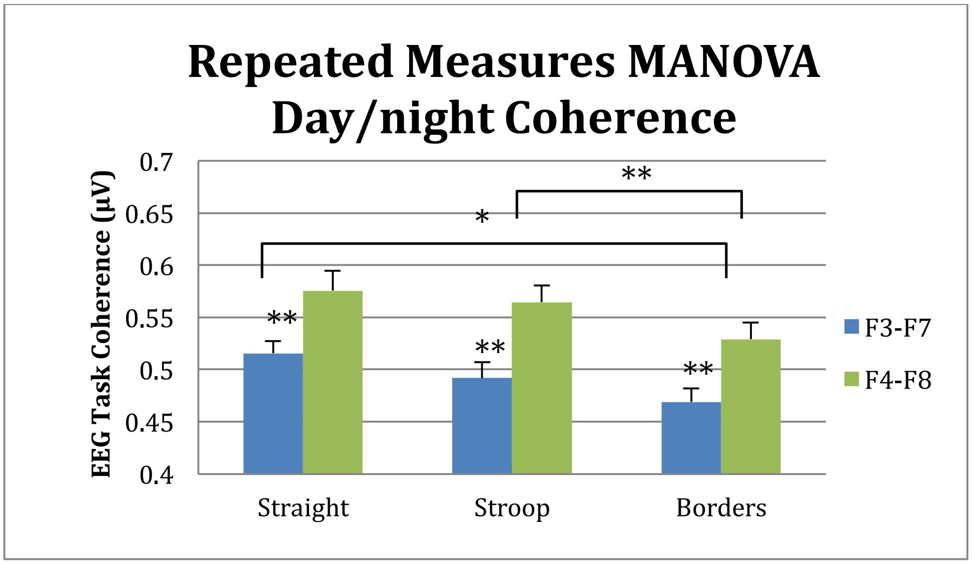
Figure 3. *Repeated measures MANOVA comparing lateral frontal EEG power during day/night task*

.



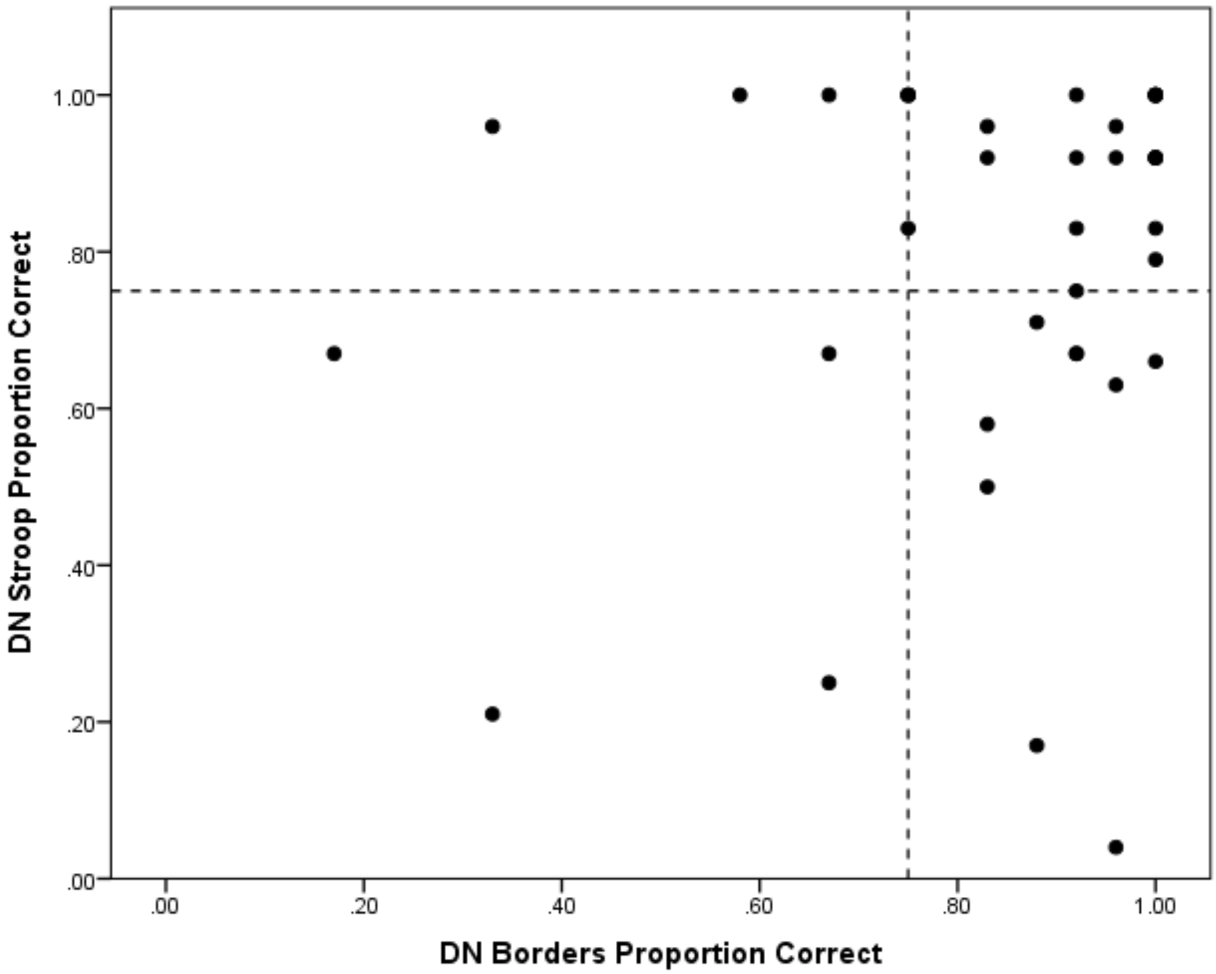
Note. **p*<.05. ***p*<.01.

Figure 4. *Repeated measures MANOVA comparing fronto-frontal EEG coherence during day/night task.*



Note. **p*<.05. ***p*<.01.

Figure 5. *Scatter plot of performance on Stroop and borders condition of the day/night task.*



Note. Dotted lines at 75% correct signify passing the task.

Appendix A

Office of Research Compliance
Institutional Review Board
North End Center, Suite 4120, Virginia Tech
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-4606 Fax 540/231-0959
email irb@vt.edu
website http://www.irb.vt.edu

MEMORANDUM

DATE: March 22, 2016

TO: Martha Ann Bell, Alleyne Ross, Leslie Ann Patton, Tashauna Louise Blankenship, Ran Liu, Cassondra Mayve Eng

FROM: Virginia Tech Institutional Review Board (FWA00000572, expires January 29, 2021)

PROTOCOL TITLE: Inhibitory Control In Preschool Aged Children

IRB NUMBER: **15-335**

Effective March 22, 2016, the Virginia Tech Institution Review Board (IRB) Chair, David M Moore, approved the Continuing Review request for the above-mentioned research protocol.

This approval provides permission to begin the human subject activities outlined in the IRB-approved protocol and supporting documents.

Plans to deviate from the approved protocol and/or supporting documents must be submitted to the IRB as an amendment request and approved by the IRB prior to the implementation of any changes, regardless of how minor, except where necessary to eliminate apparent immediate hazards to the subjects. Report within 5 business days to the IRB any injuries or other unanticipated or adverse events involving risks or harms to human research subjects or others.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

http://www.irb.vt.edu/pages/responsibilities.htm

(Please review responsibilities before the commencement of your research.)

PROTOCOL INFORMATION:

Approved As:	**Expedited, under 45 CFR 46.110 category(ies) 4,5,6,7**
Protocol Approval Date:	**April 10, 2016**
Protocol Expiration Date:	**April 9, 2017**
Continuing Review Due Date*:	**March 26, 2017**

*Date a Continuing Review application is due to the IRB office if human subject activities covered under this protocol, including data analysis, are to continue beyond the Protocol Expiration Date.

FEDERALLY FUNDED RESEARCH REQUIREMENTS:

Per federal regulations, 45 CFR 46.103(f), the IRB is required to compare all federally funded grant proposals/work statements to the IRB protocol(s) which cover the human research activities included in the proposal / work statement before funds are released. Note that this requirement does not apply to Exempt and Interim IRB protocols, or grants for which VT is not the primary awardee.

The table on the following page indicates whether grant proposals are related to this IRB protocol, and which of the listed proposals, if any, have been compared to this IRB protocol, if required.

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Date*	OSP Number	Sponsor	Grant Comparison Conducted?

* Date this proposal number was compared, assessed as not requiring comparison, or comparison information was revised.

If this IRB protocol is to cover any other grant proposals, please contact the IRB office (irbadmin@vt.edu) immediately.