ELECTROPHYSIOLOGICAL MEASURES OF INHIBITORY CONTROL IN CHILDHOOD OBESITY

By

Robert Henderson

A thesis submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Honors Bachelor of Science in Psychology with Distinction.

Spring 2010

ELECTROPHYSIOLOGICAL MEASURES OF INHIBITORY CONTROL IN CHILDHOOD OBESITY

By

Robert Henderson

Approved: _____

Robert F. Simons, PhD.
Professor in charge of thesis on behalf of the Advisory Committee

Approved: _____

Steven Most, PhD.
Committee member from the Department of Psychology

Approved: _____

Christine Ohannessian, Ph.D.
Committee member from the Board of Senior Thesis Readers

Approved: _____

Alan Fox, Ph.D.
Director, University Honors Program

ACKNOWLEDGMENTS

I would like to thank everyone involved in the clinical psychophysiology lab at the University of Delaware, especially Damion Grasso, Mandy Skoranski, Jason Krompinger, and Emily Stanley. I would also like to thank Kate Chernow, Anne Healy, and Laura Szklarski for their help in consenting and running participants.

I wish to thank the members of my thesis committee, Dr. Steve Most and Dr. Christine Ohannessian. I would also like to extend a special thank you to my thesis advisor, Dr. Robert Simons, whose input and support was crucial to the completion of my thesis and greatly appreciated.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Obesity is a highly prevalent problem in the United States and has been associated with many negative health consequences. The present study sought to provide insight into the cognitive processes that could be involved in overeating. Event-related potentials (ERPs) of 11 overweight and 12 normal-weight children were measured during completion of a Stop-Signal Reaction Time (SSRT) task. The N2 and P3 components of control participants' ERPs were expected to show evidence of right-hemisphere processes involved in response-inhibition. Because specific deficiencies in these components are believed to be related to inefficient inhibitory control, it was predicted that the ERPs of overweight children would be characterized by decreased N2 component amplitudes compared to the ERPs of normal-weight controls. For trials in which inhibition was successful, it was predicted that the ERPs of overweight children would be characterized by smaller P3 amplitudes than the ERPs for normal-weight children. The results support the notion that response-inhibition involves activation of right-hemisphere processes. No significant differences were found between overweight and control children on performance data or the N2 and P3 components of ERPs elicited during the SSRT task.

Chapter 1

INTRODUCTION

1.1 Obesity in the United States

Obesity has been and continues to be a major problem in the United States. According to the Center for Disease Control (CDC), Obesity has been associated with a wide variety of health problems such as coronary heart disease, stroke, type 2 diabetes, hypertension, and some types of cancers (Levi, Segal, & Gadola, 2007). One major survey used to study obesity is the National Health and Nutrition Examination Survey (NHANES). Using data from the NHANES, researchers showed that in 2005-2006 over one-third of adults living in the United States could be considered to be obese (Ogden, Carroll, McDowell, & Flegal, 2007). Not only has the adult population become heavier overall, but those who were heaviest in 1980 have gotten much heavier (Ogden et al., 2007).

Childhood Obesity is also a major problem in the United States, with similar percentages of children being affected. Between 2003 and 2006, 11.3% of US children who were 2-19 years of age had a Body Mass Index (BMI) for age at or above the 97th percentile of BMI for age, 16.3% were above the 95th percentile, and 31.9% were above the 85th percentile (Ogden, Carroll, & Flegal, 2008). Childhood Obesity is an especially relevant problem in the state of Delaware, which was ranked 19th in the United States for rates of childhood obesity (Levi, et al., 2007). Furthermore, obesity may actually be underreported, as BMI information is generally collected from self-

report surveys and participants likely tend to over report their height and under report their weight (Levi. et al., 2007). This indicates that some of the reporting subjects may actually have a higher BMI than is actually recorded. Because of this, obesity rates could actually be higher than is typically reported, indicating that obesity is likely to be an even greater problem in the United States.

The many health factors that are associated with obesity and the high percentage of obese adults and children in the United States provide ample evidence that obesity is a particularly relevant problem. Research on overweight individuals may be able to give a better understanding of the factors that could put one at risk for becoming overweight, which could help to provide insight into new interventions.

1.2 Obesity and Inhibition

There has been little research on the cognitive processes behind overeating, with the focus instead being on providing access to healthy alternatives. However, providing access to healthy alternatives to overeating, such as exercise, will only work if overweight individuals choose to take advantage of them. A different approach is to investigate the neuro-cognitive correlates of obesity to determine whether overeating could be associated with reduced inhibitory control or attentional deficiencies.

Individuals who are overweight could have less efficient inhibitory control mechanisms compared to normal-weight individuals. Although there has not been much research on the actual neuro-cognitive correlates behind overeating, some studies have found that there is an association between inhibition deficiencies and obesity. For example, Braet, Claus, Verbeken, and Vlierberghe (2007) found that overweight children generally responded more impulsively and reported greater

difficulties in shifting attention when compared to normal weight children. Interestingly, the study also found that overweight boys seemed to show many symptoms of ADHD, including increased impulsivity, hyperactivity, and inattention. Although impulsivity and deficient inhibition are not the same construct, they are likely to be related and it seems reasonable to predict that overweight children may have less efficient inhibitory control mechanisms compared to normal weight children.

There has also been some evidence for increased cognitive difficulties in dieting individuals compared to non-dieting individuals. Kemps, Tiggemann, & Marshall (2005) found that dieting individuals had worse performance on a variety of cognitive tasks than did non-dieting individuals, indicating that weight-loss dieting may have an impact on central executive functioning that is fairly global. If weight-loss dieting has the general effect of impairing central executive functioning, it will likely have consequences on specific cognitive functioning processes, such as inhibition. By researching specific cognitive processes that may be involved in overeating and weight-loss dieting, a better understanding of the neuro-cognitive correlates associated with overeating could be obtained.

If children who are having trouble managing and regulating their weight are found to have less efficient inhibitory control abilities than normal weight children it could help to encourage new and more effective therapies aimed at increasing an overweight individual's efficiency at inhibiting a response. Cognitive Control Training (CCT) has been shown to help improve working memory, alleviate depression, and increase attentional control (Siegle, Chinassi, & Thase, 2007). If children who are overweight are found to have less efficient inhibitory control mechanisms, CCT might be able to help teach them to shift their attention in a way that would allow more

efficient inhibitory control. One way of measuring the efficiency of inhibitory control is through a Stop-Signal Reaction Time (SSRT) task.

1.3 The SSRT task

In a SSRT task, participants are required to interrupt ongoing actions in response to the presentation of a stop-signal, such as a tone or red dot (DeJong, Coles, Logan, & Gratton, 1990). The SSRT task employs a reaction time task in which the participant responds to an initial or "go" stimulus. When the go stimulus is presented to a participant a set of "go" processes are believed to occur which include recognizing the stimulus, choosing how to respond, preparing to respond, and executing the response itself (DeJong et al., 1990). On some trials, a stop-signal instructs the participant to inhibit his or her response to the initial stimulus (i.e. not pressing a button). This stop-signal occurs at varying delays following the initial stimulus presentation in an effort to obtain a successful stop rate of approximately 50%. When the SSD is longer (i.e. the stop-signal occurs later in time after initial stimulus presentation) the participant is less likely to successfully inhibit his or her response to the initial stimulus (DeJong et al., 1990). When a stop-signal is presented, a second set of processes (the "stop" processes) occur, which are believed to include recognizing the stop-signal and withholding of the initial response (DeJong et al., 1990). The Race Model, which involves a "race" between the "go" and "stop" processes, is used to evaluate performance on the SSRT task.

1.3.1 The Race Model

Performance on the SSRT task is evaluated using the Race Model, which has two assumptions. The first assumption of the Race Model is that the go and stop-

signal processes proceed independently of one another and the second is that the time needed to process a stop-signal is constant (DeJong et al., 1990). Whether a response occurs on each trial depends on whether the go or stop process finishes first. If the go process finishes first, the participant will respond even though there was a presentation of the stop-signal. This is an Unsuccessful Stop Trial (USST). If the stop processes finish first, the participant will be able to inhibit their initial response and no response will occur. This is referred to as a Successful Stop Trial (SST). The SSRT is a measurement of the amount of time needed for the stop process to reach completion after presentation of the stop signal. More inhibitory failures or a longer SSRT during the stop task would indicate behavioral evidence of a reduced level of inhibitory control. It was hypothesized that individuals going through the weight management program would have a longer SSRT during the stop task compared to normal-weight controls. It was further hypothesized that WM participants with higher age-adjusted BMIs would have longer SSRTs.

1.4 Event-Related Potentials

Although behavioral measures can provide support for efficiency of inhibition when observable changes in behavior are present, behavioral measures alone do not let us make distinctions between the precise stages involved in inhibiting a response. There are many processes that must happen before inhibition is achieved, which could include reception of sensory information, stimulus reception and recognition, its translation into an effective control mechanism, and the actual act of inhibiting the initial motor response. Behavioral data alone can provide support for the efficiency of inhibition through differences in reaction times to the stop-signal, but the SSRT only represents a global mechanism of inhibition. Electrophysiological

methods, such as Event-Related Potentials (ERPs), are superior to behavioral measures alone because they can show a more complete description of the underlying processes involved in inhibition by providing a better understanding of the different mechanisms that occur during the SSRT task.

By using electrophysiological methods, changes in the processing of information can be recorded and observed even when there are no obvious behavioral differences present. Electrophysiological methods can measure neural activation that is associated with certain cognitive processes (Banashewski & Brandeis, 2007). Some of these methods have excellent timing resolution, whereas others have excellent spatial resolution. These techniques are also in demand because they are non-invasive and have the ability to provide real time monitoring of brain processes (Banaschewski & Brandeis, 2007). By using different electrophysiological techniques, a better understanding of the brain processes that occur during a given task can be obtained.

Electrophysiological measures, such as electroencephalogram (EEG), magnetoencephalography (MEG), and functional magnetic resonance imaging (fMRI), each have their own advantages and disadvantages. For example, fMRI can show the precise location of brain activation by measuring blood flow in the brain, but has poor timing resolution. EEG recordings have the advantage of providing highly accurate temporal resolution but can only offer predictions of where the brain activation occurs.

EEG measures the activity of neurons in the brain and allows the monitoring of "spatio-temporal activation in the brain during sensory, cognitive, affective, attentional and motor information processing" (Banaschewski & Brandeis, 2007). EEG is not useful in and of itself because of the many signals from neurons firing throughout the brain on a regular basis. Instead, researchers calculate ERPs in

order to isolate the signal of interest from the background noise of other neurons that are firing throughout the brain. Using EEG data to form ERPs has the advantage of allowing the analysis of different kinds of stimuli within a given trial of an experiment, which makes it possible to perform mixed-trial analysis of SST and USST during the same trial (Liotti, Pliszka, Perez, Kothmann, & Woldorff, 2005).

ERPs are obtained by time-locking the recording of the EEG around a given event, such as a stimulus, and then averaging many trials of EEG recording around that stimulus. These ERPs are believed to be representative of "sensory, motor, and cognitive processing during the unfolding of cognitive tasks" (Liotti, et al., 2005). The ERP is reflective of the electrical changes that are associated with a given stimulus and provides a representation of the signal of interest.

In order to research the cognitive processes associated with overeating, ERPs associated with inhibitory control will be recorded during the SSRT task. Certain ERP components are believed to be associated with the processing of information and the stages at which that processing occurs. These components can be identified and associated with a specific cognitive activity, which can help us to predict what stage of processing may be responsible for any observed behavioral differences. In particular, the N2 and P3 components of the ERP associated with a SSRT task are believed to be related to inhibition.

1.4.1 The N2 Component

The N2 component of an ERP is a sharp negative amplitude waveform that tends to occur approximately 200ms after the stop-signal is presented during the SSRT task. Pliszka, Liotti, and Woldorff (2000) used a SSRT task to investigate differences in efficiency of inhibitory control of children with ADHD compared to

control children of similar ages. The results of this study indicate that the N2 component elicited by normal control children during the SSRT task has a right-hemisphere frontal scalp distribution that is similar in amplitude on SSTs and USSTs. Because of this, it was hypothesized that regardless of trial type, control children would have greater N2 amplitudes on right-hemisphere sites than on left-hemisphere sites.

Although the N2 component did not vary by trial type in this study, there were group differences between ADHD participants and control participants (Pliszka et al., 2000). The N2 component was smaller in amplitude for children with ADHD than for healthy controls, and was associated with decreased behavioral performance during the SSRT task (Pliszka et al., 2000). The N2 component has been interpreted as being the "red flag" that signals the need for response-inhibition regardless of the trial outcome (Pliszka et al., 2000). This red-flag occurs too late following the stop-signal to be due solely to characteristics of the stimulus, and instead is probably a reflection of the recognition and triggering of inhibitory processes that need to occur in response to the stop-signal. Since the N2 is believed to reflect the need for initiation of inhibitory processes, it was hypothesized that overweight children would have N2 components that were lower in amplitude than normal weight controls on both types of trials.

1.4.2 The P3 Component

The P3 elicited during the SSRT task is believed to be associated with an individual's efficiency of inhibitory control. Individuals tend to have a P3 component that occurs earlier and with greater amplitude during SSTs than USSTs (Kok, Ramautar, DeRuiter, Band, & Ridderinkhof, 2004). Using a pediatric sample, Liotti, et

al., (2005) found a greater amplitude P3 component on SSTs than USSTs. P3 component amplitude on SSTs was reduced in children with ADHD compared to controls' P3 amplitude on SSTs. The P3 component is believed to reflect the "more efficient monitoring or successful implementation of the process of response inhibition" (Liotti et al., 2005). If the N2 component represents the "red flag" that signals the need for the onset of inhibitory processes, then the P3 component can be conceptualized as the "brake" that puts those processes into effect (Pliszka et al., 2000). If the "brakes" on a car are worn down, they will be less efficient and less likely to prevent a collision. Using the same logic, if the P3 "brake" is less efficient it will be less likely to prevent the on-going motor response from occurring.

If overweight children have trouble inhibiting an ongoing action due to inefficient monitoring or implementation of inhibition-related processes, there should be decreased P3 component amplitude for WM participants during SSTs compared to the P3 amplitude of normal-weight controls on SSTs. It was hypothesized that all subjects would have an earlier occurring P3 component during SSTs than during USSTs, and that this component would be of higher amplitude on SSTs than USSTs for control participants. It was further hypothesized that WM ERPs would be characterized by P3 components on SSTs that were lower in amplitude compared to normal-weight children's P3 component amplitudes during SSTs.

1.5 Summary

In summary, the present study sought to find evidence of differences in neuro-cognitive correlates of overweight children compared with normal-weight, age- and gender-matched controls. To determine whether BMI has an impact on inhibition efficiency, it was hypothesized that WM subjects who had higher BMIs would have

increased SSRTs. WM subjects were hypothesized to have a longer SSRT compared to control subjects, which would provide evidence of a general deficiency in inhibitory control.

To research processes and mechanisms behind the general index of inhibitory control represented by SSRT data, ERP components can be calculated and compared. Regardless of trial type, control participants were predicted to have ERPs with N2 components that were greater in amplitude at right-hemisphere locations compared to left-hemisphere locations. Since the N2 component is believed to be the "flag" that triggers the need for the initiation of inhibitory processes, N2 amplitude was predicted to be reduced in WM participants relative to the N2 component of control subjects. For all subjects, it was hypothesized that the P3 maximum amplitude would occur earlier on SSTs than on USSTs. For control participants, it was predicted that the P3 amplitude on SSTs would be larger than the P3 amplitude on USSTs. Because the P3 component elicited during SSTs is believed to represent the "brake" (i.e., the monitoring and implementation of inhibition), it was predicted that WM children would have decreased P3 component amplitude on SSTs compared to the P3 component amplitude of control children during SSTs.

Chapter 2

METHODS

2.1 Participants

Participants for this study were 19 children and adolescents ages 7-17 who were enrolled in treatment and intervention at the Pediatric Weight Management Clinic at A.I. DuPont Hospital for Children and 15 participants from the surrounding community who were matched with the Weight Management participants for age, sex, and socioeconomic status. Five of the participants from the surrounding community were recruited through Primary Care at A.I. DuPont Hospital for Children and ten participants from the surrounding community were recruited by inviting participants from a previous study to be involved in the experiment. Participants who were recruited through A.I. DuPont Hospital for Children were paid 80 dollars upon completion of the experiment. Participants who were recruited from a previous study were paid 40 dollars when they finished the experiment. All participants assented to being involved in the experiment and their primary caregivers gave informed consent.

2.2 Stimuli and Procedure

Participants performed a SSRT task that was counterbalanced with a second task. Visual stimuli were presented on a Pentium I class computer. Presentation software (Neurobehavioral Systems, Inc) was used to regulate the presentation and timing of stimuli and to measure reaction times.

The SSRT task has “go” and “stop” trials that were presented randomly. The Go trials consisted of green colored arrows that pointed either to the right or left of the screen for 1000ms. Participants were required to press the left button on a response pad if the arrow was pointing to the left and the right button if the arrow was pointing to the right. Participants were instructed to respond both quickly and accurately.

The stop trials used the same initial stimuli as the go trials, but when the go stimulus was on the screen a red circle (the stop signal) was superimposed onto the arrow at varying delay intervals. Participants were instructed to inhibit their response to the go stimulus if the stop signal was presented. A successful stop occurs when the ongoing motor response is cancelled and an unsuccessful stop occurs if the participant makes a response. The stop and go trials occurred randomly so that the participant did not know whether a stop signal would appear or not.

The SSRT task employs four blocks consisting of 100 trials each. Each block consists of an approximately equal number of arrows that point to the left and right. Stop trials occurred randomly during each of the four blocks and made up about 1/3 of all of the trials. Participants first completed two 50 trial practice blocks, during which they were instructed to work quickly and accurately while being aware that they may need to inhibit their response if a stop signal appeared. A tracking procedure that varied the delay between go and stop signals was used. If the participant successfully inhibited a response the delay on the next stop trial was increased by 50 ms. If the participant was unable to inhibit a response the delay for the next stop trial was decreased by 50 ms.

The SSRT is believed to be a measure of the latency of the inhibitory process. The SSRT cannot be observed directly and so it is estimated (Logan & Cowan, 1984). The best estimate of the SSRT can be found when there are inhibitory failures on about 50% of all of the stop trials (Band, Maurits, & Logan, 2003). By using the tracking procedure to vary the SSD this error rate will usually be reached. To compute the SSRT the mean SSDs were then subtracted from the mean go reaction time.

2.3 Electrophysiological Recording

After participants consented to participate, electrophysiological recording was performed using a 32-channel shielded waveguard electrode cap which was placed on the participant's head. Research Assistants used a blunt tipped syringe to insert gel in between each electrode and the participant's scalp. The gel was used as a conducting agent to make sure that there was low impedance between the scalp and the electrode. Impedances were kept below 20 KΩ. The electroencephalogram (EEG) was then recorded through the electrodes of the cap using ASA software from ANT. Trials were rejected if the participant had reaction times that were too long or too short or if the electrophysiological activity of a recording channel changed by more than 75 microvolts from the trial average. The EEG data were low-pass filtered at 20 Hz and high-pass filtered at 0.1 Hz.

2.4 Data Reduction and Analysis

An ERP is a measure of the msec by msec changes that occur in the background EEG that is related to stimulus delivery and response execution. ERPs can be extracted from the EEG by averaging many trials and then locking the averaging to

a stimulus or response. By time-locking the averaging over many repetitions of the same event EEG data that is unrelated to the event will average to zero and the signal of interest can be observed. The ERP that is obtained has a variety of components, but the N2 and P3 components for successful and unsuccessful stop trials were the main points of interest.

Since the ERPs elicited by stop and go signals occur very close in time , it is necessary to separate them from one another. This was done using a method similar to that used by DeJong et al, (1990). There are two types of "go" ERPs: "Fast-go" ERPs are characterized by a quick response to the go stimulus whereas "Slow-go" ERPs occur when participants respond slowly to the go stimulus. To determine the cut-off point for fast and slow go ERPs, accuracy on stop-signal trials was calculated and multiplied by the number of "go" trials (i.e., trials in which a stop-signal did not occur). Responses that occurred earlier than this point were labeled "fast-go" ERPs and responses that occurred after this point were labeled as "slow-go" ERPs.

The race model assumes that ERPs on go trials are similar to ERPs elicited by the go stimulus during stop-signal trials Stop-signal ERPs (SST and USST) are time-locked to the stop-signal and "go" EEGs are averaged separately for "Fast-go" and "Slow-go" ERPs. Because the timing of cognitive processes underlying fast and slow 'go' trials is different, it stands to reason that the ERPs associated with the two trial types would also be different, and empirically this is indeed the case. Therefore, to isolate the ERPs to the stop signals, "slow-go" ERPs were subtracted from SST ERPs and fast-go ERPs were subtracted from USST ERPs. These pairings follow from the race model such that a successful stop would occur during trials on which the underlying go process must be slow, while the unsuccessful stop trials would occur on

trials associated with particularly fast go processes. These difference waves resulted in pure stop-signal ERPs that were free of residual ERP activity to the go-stimulus.

The N2 and P3 components respective latencies were then quantified and scored by analyzing the point at which the waveform reached its minimum N2 amplitude and maximum P3 amplitude in a given window in time. The window for the P3 component ranged from 250-400 ms and the window for the N2 component ranged from 120-200 ms. In order to baseline correct these values, the mean activity 0-200 ms before the stop-signal presentation will be subtracted from the N2 and P3 component's respective minimum and maximum amplitudes. This resulted in values for the N2 and P3 component's amplitudes and latencies.

2.5 Statistical Analysis

To compare the behavioral data, an independent samples t-test was performed to compare the WM group's average SSRT to the control group's average SSRT. Simple correlations were performed to determine if the age-adjusted BMI of WM participants was related to their respective SSRTs.

To evaluate the quantified scores of the N2 and P3 components, SPSS (Version 16.0) General Linear Model software was used with p values of .05 deemed significant for the resulting repeated measure ANOVA comparisons.

Chapter 3

RESULTS

3.1 Behavioral Results

Table 1 shows participant demographics and behavioral results that were used for data analysis. WM participants had a mean SSRT of 261 ms and PC participants had a mean SSRT of 229.87 ms. However, independent-sample t-tests not assuming equal variance did not reveal this to be a significant difference (p=.195). There was no correlation between WM participant's age-adjusted BMI and SSRT values (p=.974). There was not a significant difference in variability in SSRT between WM and control participants (p=.194).

Table 3.1 Participant Demographics and Behavioral Data.

	WM	Control	p-value
Number of Participants	18	15	
No. Male	6	5	
No. Female	12	10	
Ages	12.67 (2.425)	12.53 (2.588)	.590
SSRT	261 (83.34)	229.87 (49.83)	.195

Standard Deviations are shown in Parentheses.

3.2 ERP Results

ERP analysis included EEG and SSRT data from 23 participants in total. In the WM group, one participant was removed for not making enough responses (i.e. for not responding on go trials more than 40 times) during the SSRT task and 7 were removed for having too many artifacts in their EEG data (i.e., if more than 20% of the participant's trials were eliminated during data reduction). In the control group, three participants were removed from ERP analysis due to having too many artifacts. After removal of participants with unusable data, 11 WM participants and 12 control participants remained for ERP analysis. Table 2 shows participant demographics and mean SSRT results of participants whose data was used for ERP analysis. Independent t-tests no assuming equal variance accounted for did not reveal significant SSRT differences between WM and Control participants (p=.756).

Table 3.2 Demographics and behavioral results of participants with usable ERP data.

	WM	Control
Number of Participants	11	12
No. Male	3	4
No. Female	8	8
Age	13.09	13
SSRT (ms)	222.45 (51.850)	216.75 (35.379)

Standard Deviations are shown in Parentheses.

3.2.1 N2 Component Results

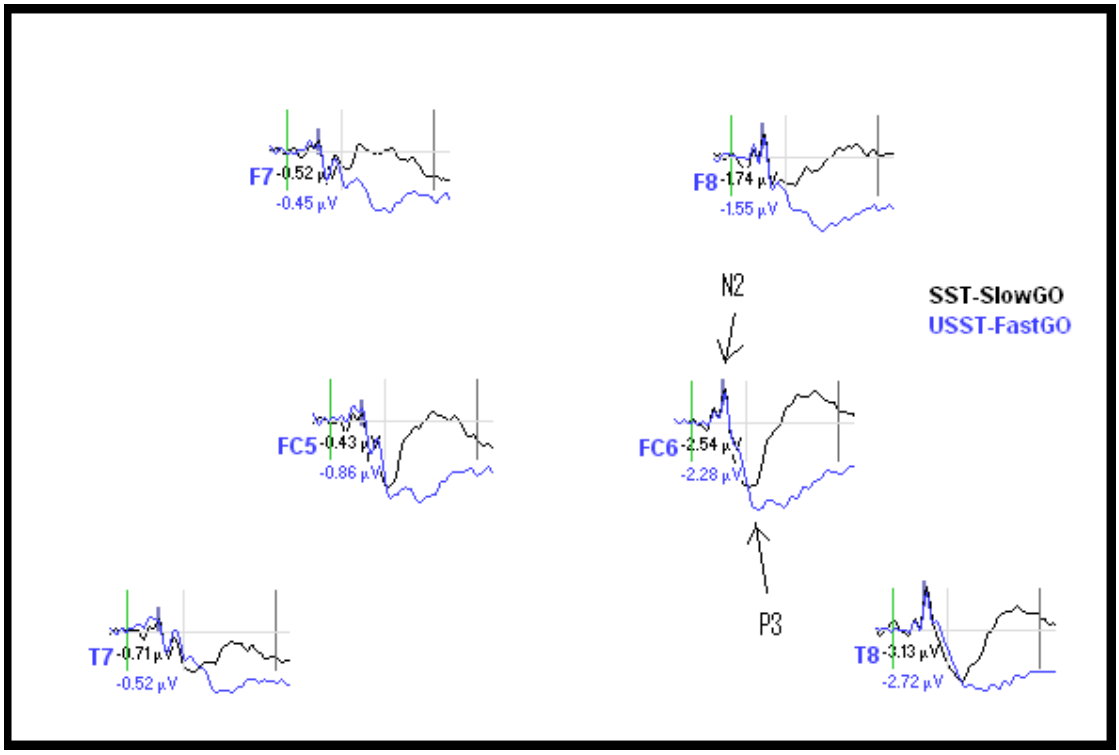

Figure 3.1 Headplots of ERPs for SST and USST by site location.

ERP waveforms from left and right frontal (F7, F8), central (FC5, FC6) and temporal (T7, T8) used to analyze the N2 component are presented in Figure 1. To determine whether there was a laterality effect on N2 component amplitude, the ERPs of the three electrodes at left-hemisphere locations for each participant were averaged together to form a "left-hemisphere" ERP and the three corresponding ERPs from electrodes on the right side were averaged together to form a single "right-hemisphere" ERP.

Analysis of Variance (ANOVA) on all participants (n=23) revealed an N2 component that was higher in amplitude (i.e. more negative) at right-hemisphere sites than at the left-hemisphere sites ($p<.001$). The mean amplitudes for each site and condition are shown in Table 3. The amplitude of the N2 component did not vary by group ($p=.848$) or condition ($p=.741$) alone, although differences did approach significance when including trial type, channel location, and group ($p=.077$).

Table 3.3 Mean minimum amplitudes of the N2 component by hemisphere location and trial type.

Hemisphere	Condition	Mean (microvolts)	Std. Deviation
Left	SST	-2.389	1.910
	USST	-2.224	1.986
Right	SST	-3.769	2.084
	USST	-3.763	2.46

3.2.2 P3 Component Results

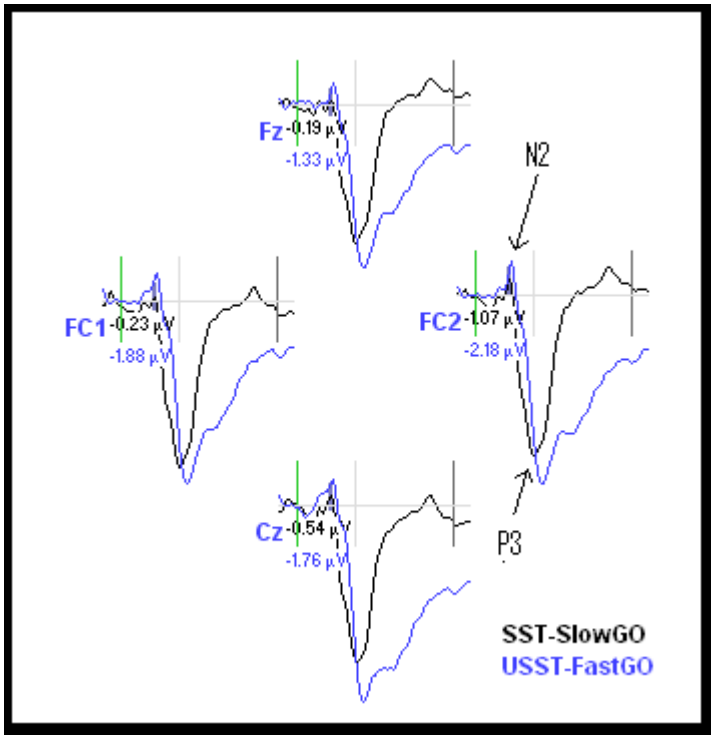

Figure 3.2 Headplots of the channels used to compare P3 component amplitude and latencies on SST and USST.

ERPs for electrodes used to analyze the P3 component are presented in Figure 2. To compare participant and trial-type factors with P3 component amplitude and latency, four fronto-central electrodes were averaged together for each participant to form a single ERP waveform. The channels averaged to form this ERP waveform were Fz, FC1, FC2, and Cz.

Results showed that the P3 component occurred earlier on SST than on USST. The average latency of the P3 component of all participants on the SST was

304.965 ms and the average latency on USST was 337.388043 ms. Multivariate Tests (n=23) revealed a significant difference between these two latencies ($p<.005$) (see Figure 2). There was not a significant group difference on P3 latency either successful or unsuccessful stop trials.

The mean amplitude of the P3 component on SST for all participants was 13.33 microvolts (sd= 7.35). On USST, the mean amplitude of the P3 component was 14.79 microvolts (sd= 7.33). This amplitude difference was not significant nor did ANOVA reveal any group differences on P3 amplitude in general (p=..515) or as a function of trial type (p=.714).

Chapter 4

DISCUSSION

Results from the current study indicate that the SSRT procedure worked as expected. Behavioral results revealed a non-significant correlation between groups and SSRTs. This difference was in the hypothesized direction, with WM participants tending to have mean SSRTs that were longer compared to control participants' mean SSRTs and the computed SSRTs were comparable to those reported in other studies of children in this age range (e.g. Liotti, Pliszka, Higgins, Perez, & Semrud-Clikeman, 2010; Liotti et al., 2005; Pliszka et al., 2000).

ERP components also indicated that the SSRT procedure worked effectively. First, the N2 component was present and larger in the right hemisphere, as evidenced by the highly significant difference between amplitude of the N2 component in right-hemisphere compared to left-hemisphere sites. This is consistent with previous studies suggesting that mechanisms of response-inhibition during the SSRT task are lateralized (e.g. Liotti et al., 2010, Liotti et al., 2005, Albrecht, Banaschewski, Brandeis, Heinrich, & Rothenberger, 2005). Although N2 amplitude did not differ between the WM and control participants, the amplitude of the N2 component for both groups was similar during SSTs and USSTs. The amplitude of the N2 component was unaffected by whether successful inhibition was achieved, providing evidence that the N2 component is representative of an early process involved in evoking inhibitory control. This provides support for the idea of the N2 as a "red flag" that signals the need for initiating inhibitory processes.

Second, there was a significant difference in the latency of the P3 component on SSTs and USSTs. As predicted, the P3 component occurred earlier for SSTs than for USSTs. Kok et al. (2004) point out that longer latencies of the P3 component for USST compared to SST provide evidence that response-inhibition on a given SSD could depend on the "timing of the internal response to the stop signal" instead of solely on the speed of processing the stimulus. When the P3 component occurs early (on SSTs) it is reasonable to assume that concurrent activation ('go') processes are prevented from leading to a behavioral response, whereas when the P3 component occurs late (on USSTs), it is likely too late to disrupt those activation mechanisms. Although we hypothesized that the P3 component of WM participants' ERP on SST would differ from that of the control participants, no evidence of this was found in the current study on either the P3 latency or amplitude measure. The hypothesis that participants in the present study would have larger maximum P3 amplitude during SSTs compared to P3 amplitude on USSTs, therefore, was not met. In fact, the means were in the opposite direction. This is inconsistent with other studies currently underway in the same laboratory with samples of normal young adult participants (Krompinger, in preparation; Stanley, in preparation).

This experiment was limited by relatively small sample sizes and the consequent lack of power to detect real effects. It is possible that increasing the number of participants in each group could reveal more robust differences in SSRT or ERP components. It is also possible that more significant group differences in mean SSRTs could be revealed using different types of analyses. For example, Pliszka et al. (2000) found an insignificant trend toward slower SSRT for ADHD participants than control participants, but used a response-inhibition curve to show that ADHD

participants performed significantly more poorly on longer SSDs than did control participants. Although the present experiment did not calculate a response-inhibition curve, it is possible that a more sophisticated analysis such as theirs might yet indicate evidence of inhibitory control deficiencies of WM participants.

A second limitation of this experiment was the removal of many participants from the ERP data analysis. This was especially true for the WM group. After removal of participants, SSRTs of the WM and control group were much more similar. As just mentioned, Pliszka et al. (2000) reported an insignificant trend toward slower SSRTs in ADHD children compared to control children; at the same time, however, they still found significant differences in ERP components between groups. In the present experiment, a subgroup of WM participants characterized by longer SSRTs and with many artifacts in their ERP data were removed, which reduced the mean SSRT of the WM group for the analysis of ERP components. WM participants who were removed from ERP analysis because of unusable data may have been those with less efficient inhibitory control, and had they been included we may have been able to reveal significant differences in ERP components.

Although this particular version of the SSRT procedure looks for inhibitory deficits, it is important to realize that a general inhibitory deficit in WM participants may not exist. The SSRT task in the present study involved evoking inhibitory control to fairly general stimuli. However, it might also be possible that WM children have inhibitory deficits that are specific to certain cues rather than a general deficiency in inhibitory control.

To determine whether WM children have deficits in the efficiency of inhibitory functioning that are related to certain types of stimuli, future studies could

modify the SSRT task to include cue-related stimuli. Preoccupying concerns with food, body, and weight could have a relatively large impact on cognitive functioning (Kemps et al., 2005). The current SSRT task could be modified to include images of food in order to determine whether inhibitory deficiencies could exist that are specific to food cues. This study should make use of different types of cue-related stimuli, including arousing, neutral, and food-related images. Using images that are of similar positive valence to the food-cues can help to determine if WM children have deficient inhibitory control mechanisms specific to food-cues or to positive attention-grabbing cues, such as images of babies, puppies, and other "cute" pictures.

At the same time, it is important to realize that even if differences in efficiency of inhibition emerge with larger group sizes it will still be difficult to determine whether those differences are a consequence of being overweight or a consequence of weight-loss dieting. For example, Kemps et al. (2005) found that self-regulation by individuals who were dieting was associated with a decreased performance on a variety of Central Executive tasks. To determine whether differences in the WM group were a general consequence of being obese or were due to the effects of dieting, future studies should recruit an additional group of participants who meet the criteria for obesity but are not active in a WM program or dieting.

The results from the present study indicate that the SSRT task is a valid measurement of inhibitory control. The "red flag" N2 component was found to have a right-hemisphere scalp distribution followed by an earlier-occurring P3 "brake" component during SSTs than during USSTs. Differences in the P3 component amplitude on SSTs and USSTs were not revealed. There was a near-significant interaction between group, laterality, and trial-type on N2 amplitude and it could be

beneficial to investigate this possible interaction with larger sample sizes to gain a better understanding of what the N2 may represent. Although there were not any significant group differences between WM participants and control participants, future research aims to determine if there may be cue-related differences in efficiency of inhibitory control specific to food stimuli.

REFERENCES

Albrecht, B., Banaschewski, T., Brandeis, D., Heinrich, H., & Rothenberger, A. (2005). Response inhibition deficits in externalizing child psychiatric disorders: An ERP study with the stop-task. Behavioral and Brain Functions, 9, 1-22.

Banaschewski, T. & Brandeis, D. (2007). Annotation: What electrical brain activity tells us about brain function that other techniques cannot tell us – a child psychiatric perspective. Journal of Child Psychology and Psychiatry. 48, 415-435.

Band, G. P. H., Maurits, W. M., Logan, G. D. (2003). Horse-race model simulations of the stop-signal procedure. Acta Psychologica, 112, 105-142.

Braet, C., Claus, L., Verbeken, S., & Vlierberghe, L. V. (2007). Impulsivity in overweight children. European Child & Adolescent Psychiatry. 16, 473-483.

DeJong, R., Coles, M. H., Logan, G. D., & Gratton, G. (1990). In search of the point of no return: the control of response processes. Journal of Experimental Psychology: Human Perception and Performance. 16, 164-182.

Kemps, E., Tiggemann, M., & Marshall, K. (2005). Relationship between dieting to lose weight and the functioning of the central executive. Appetite. 45, 287-294.

Kok, A., Ramautar, J. R., Deruiter, M. B., Band, G. H., & Ridderinkhof, K. R. (2004). ERP components associated with successful and unsuccessful stopping in a stop-signal task. Psychophysiology. 41, 9-20.

Krompinger, J. (in preparation) Towards a comprehensive electrophysiological investigation of cognitive control in depression.

Levi, J. Segal, L. M., & Gadola, E. (2007). F as in fat: How obesity policies are failing in America. Report from Trust for America's Health.

Liotti, M., Pliszka, S. R., Perez, R., Kothmann, D., Woldorff, M. G. (2005). Abnormal brain activity related to performance monitoring and error detection in children with ADHD. Cortex. 41, 377-388.

Liotti, M., Pliszka, S. R., Higgins, K., Perez, R., & Semrud-Clikeman, M. (2010). Evidence for specificity of ERP abnormalities during response inhibition in ADHD children: A comparison with reading disorder children without ADHD.

Logan, G. D., & Cowan, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. Psychological Review, 91, 295-327.

Ogden C. L., Carroll M. D., McDowell M. A., Flegal K. M. Obesity among adults in the United States – no change since 2003—2004. (2007). NCHS data brief no 1. Hyattsville, MD: National Center for Health Statistics.

Ogden C.L., Carroll M.D., Flegal K. M. (2008) High Body Mass Index for Age among US Children and Adolescents, 2003—2006. JAMA, 299(20):2401—2405.

Pliszka, S. R., Liotti, M., & Woldorff, M. G. (2000). Inhibitory control in children with attention-deficit/hyperactivity disorder: Event-related potentials identify the processing component and timing of an impaired right-frontal response-inhibition mechanism. Biological Psychiatry, 48, 238-246.

Siegle, G. J., Ghinassi, F. & Thase, M. E. (2007). Neurobehavioral therapies in the 21st century: Summary of an emerging field and an extended example of cognitive control training for depression. Cognitive Therapy and Research. 31, 235–262.

Stanley, M. (in preparation). Inhibitory Control in Obsessive-Compulsive Undergraduates.