THESIS

ATTENTIONAL DEMANDS DO AFFECT AMPLITUDES OF N1 AND N2 IN THE SENSORY GATING PARADIGM IN NEUROTYPICAL ADULTS AND CHILDREN

Submitted by

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In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Fall 2012

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ABSTRACT

ATTENTIONAL DEMANDS DO AFFECT AMPLITUDES OF N1 AND N2 IN THE SENSORY GATING PARADIGM IN NEUROTYPICAL ADULTS AND CHILDREN

Past research has shown that N1 and N2 ERP components may be related to attention; however, few studies have measured N1 and N2 amplitudes when attention was manipulated. In this study, two ERP sensory gating paradigms were used in which attention was manipulated by requiring participants either to focus their attention on the auditory stimuli (FA) or to watch a movie that distracted them from the auditory stimuli (SGM). To examine the relationship of N1 and N2 amplitudes to performance on three types of attention (selective, sustained, and control/switch) all participants completed the Test of Everyday Attention for Children (TEA-Ch). Participants were 23 healthy adults aged 20-30 and 20 typically developing children aged 6-10. Across both groups, N1 amplitude was significantly larger for the FA compared to the SGM paradigm, $F(1, 36) = 40.62$, $p < .001$, and for the first click compared to the second, $F(1, 36) = 40.62$, $p < .001$. Adults showed larger N1 amplitudes compared to children and group main effect approached but did not reach significance, $F(1,36) = 3.211$, $p = .082$. Across both groups, N2 amplitude showed a trend for being larger in the SGM compared to the FA paradigm, $F(1, 23) = 3.91$, $p = .06$, and the first click was significantly larger than the second, $F(1, 23) = 22.38$, $p < .001$. Adults showed a trend for larger N2 amplitudes compared to children although group main effect did not reach significance, $F(1,23) = 1.841$, $p = .188$. For N2, significant interactions for paradigm x group, $F(1, 23) = 4.12$, $p = .05$, and click x group, $F(1, 23) = 5.21$, $p = .03$ were found. Separate regression analyses controlling for group membership revealed that subtest scores from all subsystems on the TEA-Ch were significant predictors of N1 amplitude for click 2 in the FA paradigm only; selective attention and control/switch attention subtest scores were the strongest predictors. Sustained attention and control/switch attention subtest scores of the TEA-Ch significantly predicted N2 amplitudes for click 1 in the FA paradigm only. The results suggest that N1 amplitude increases when attention is directed towards the task for adults and children alike. Alternatively, N2 amplitude shows a trend for increased amplitude when attention is directed away from the stimuli and children respond differently than adults. N1 has shown that it may represent a more global type of attention while N2 may be related to an ability to dismiss information.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Dr. Patricia Davies for the incredible support that she provided throughout this process. The hours she put into patiently sharing her knowledge and expertise were invaluable in completing this project and preparing for beyond. I would also like to thank Dr. William Gavin for the many significant contributions he made to this project. His input throughout the process and assistance with statistical analyses were greatly appreciated. Additionally I would like to thank Dr. Anne Cleary for the time and insight that she provided for this thesis. The level of enthusiasm that you have all shown for research is both important and inspiring.

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CHAPTER 1

Attention

Most of everyday life's tasks require some form of attention. Nearly every activity that an individual performs requires him/her to identify what sensory information is most necessary to fully process. Whether participating in a complex task like driving through a crowded city or a routine chore such as folding laundry, a person, to some degree, will be inundated with sensory information. Without the ability to identify what one needs to focus on, process that information, and block out irrelevant information, an individual will likely have difficulty successfully completing everyday activities. The identification of attentional deficits typically relies on reports of problematic behaviors that assume there is an issue with an underlying neurological process (Manly et al., 2001). For this reason, increasing numbers of individuals, particularly children with disorders such as Attention Deficit Hyperactivity Disorder (ADHD), Autism Spectrum Disorder (ASD), and Sensory Processing Disorder (SPD) are receiving occupational therapy services for behaviors that appear to be related to deficits in attention. Recent neurological and applied research on attention is demonstrating that the definition of attention is more complex than a general state of arousal or concentration. Attention is believed to be composed of multiple abilities that can be examined as interrelated but unique processes (Posner & Petersen, 1990). Behavioral tests such as the Test of Everyday Attention (TEA) and the Test of Everyday Attention for Children (TEA-Ch), for adults and children respectively, aim to investigate an individual's capacity for these different elements of attention (Manly et al., 2001).

Elements of Attention

Posner and Peterson (1990) illustrated three distinct subsystems of attention. They identified orienting to sensory events, detecting signals for processing, and maintaining an alert state as the three major functions related to attention. Orienting is described as a covert shift in visual attention to a specified target (Posner & Peterson, 1990). Target detection refers to an individual’s ability to monitor a specific target that his/her attention is clearly oriented to and in which his/her attention is fully engaged, as opposed to a generally alert state (Posner & Peterson, 1990). Alerting is the term used to describe the “ability to prepare and sustain alertness to process high priority signals” (Posner & Peterson, 1990, p. 35). This latter process is an increased state of arousal that does not affect the accumulation of information but rather the rate of response. Thus, this type of attention leads to an enhanced reaction time based on less information, resulting in a higher rate of error (Posner & Peterson, 1990).

Mirsky, Anthony, Duncan, Ahearn & Kellam (1991); Robertson, Ward, Ridgeway, & Nimmo-Smith (1996); and Manly et al. (2001) also identify three distinct subsystems of attention that relate closely to those recognized by Posner & Peterson (1990) (see Table 1). Mirsky et al. (1991) referred to the idea of orienting as shift, target detection as focus, and alerting as sustain. Similarly, Robertson et al. (1996) and Manly et al. (2001) used the following terms to describe the same attentional types originally described by Posner and Peterson (1990): attentional switching or attentional control/shift is the conscious shift or adjustment of attention to a particular target, selective attention is the selection of a particular relevant target and inhibition of irrelevant stimuli, and sustained attention is the continued processing of a particular target over time. The TEA was developed in order to measure these separate components of attention rather than testing attention as a unitary process (Robertson et al., 1996). To better understand the TEA and the TEA-Ch, which was developed based on the TEA, each will be further discussed here.

Table 1

Description of Different Terms Used for Subsystems of Attention

Posner & Peterson, 1990	**Mirsky et al., 1991**	**Robertson et al., 1996**	**Manly et al., 2001**	*Description*
Orienting	Shift	Attentional Switching	Attentional Control/Shift	The conscious shift or adjustment of attention to a particular target.
Target Detection	Focus	Selective Attention	Selective Attention	Selection of a particular relevant target and inhibition of irrelevant stimuli.
Alerting	Sustain	Sustained Attention	Sustained Attention	The continued processing of a particular target over time.

Note. Adapted from "A test of everyday attention for children: A confirmatory factor analysis," by D. Passantino, 2011, (Master's thesis), Available from ProQuest Dissertations and Theses database. (UMI No. 1497996).

The Test of Everyday Attention (TEA)

The TEA is based heavily on the attentional model proposed by Posner and Peterson (1990). The TEA was developed to measure the different types of attention using real-life tasks such as reading maps, searching telephone directories, and listening to lottery number readings (Robertson et al., 1996). The TEA consists of eight subtests, which assess an individual's capacity for selective attention, sustained attention, attentional switching, and divided attention. While selective, sustained, and switching all relate to the three subtypes proposed by Posner and Peterson (1990) as well as Mirsky et al. (1991), the TEA additionally includes one subtest for divided attention (Robertson et al., 1996). The reason only one subtest is included for divided attention is because it is likely that a test examining divided attention would rely on a person's abilities to both sustain and switch attention (Robertson et al., 1996). For this reason, divided attention was not included as a separate subtype.

The TEA was the first clinical assessment of its kind to test the subtypes of attention in adults (Robertson et al., 1996). Since the themes of these subtests do not pertain to children as they do to adults, the applied behavioral tasks needed to be adapted in order to more appropriately address a child’s capacity for each of the subtypes of attention.

The Test of Everyday Attention for Children (TEA-Ch)

The purpose of developing the TEA-Ch was to adapt the TEA, a reliable measure of adult attention, into an assessment that could be considered appropriate for testing the same processes in children ages 6-16 years (Manly et al., 2001). The three types of attentional demands that were used by Manly et al. (2001) were based on what existed in the adult literature. The authors investigated whether their model fit with what was being seen in children and found that all three categories form a good fit based on their large sample of children beginning at age 6 (Manly et al., 2001). Since motor skill, task comprehension, and language are required for many of the tasks in the assessment, and children’s capacities for these areas vary greatly, the TEA-Ch aims to minimize or control for these differences as much as possible so that scores primarily reflect individual variations in attentional processes. Nine subtests are categorized as measures of sustained attention (5 subtests), selective attention (2 subtests), or attentional control/shift (2 subtests) so that the scores can be quantified to measure a child’s capacity for each particular type of attention.

The TEA-Ch was standardized on 293 children in Melbourne, Australia with equal numbers of boys and girls represented (Manly et al., 2001). Exclusion criteria prevented children with neurological, developmental, sensory, attentional, or learning issues from being included in the study (Manly et al., 2001). Test-retest reliability was evaluated 5 to 20 days following an initial assessment using a random subgroup of 55 children across the age ranges. Pearson’s correlations were shown to be very strong across the entire sample (ranging from .64 for the Score! subtest to .92 for the Opposite World subtest) but were much more conservative once age was partialled out (ranging from .57 for timing for the Creature Counting subtest to .85 for the Opposite Worlds subtest). In terms of validity, with the exception of the Creature Counting subtest (where seven of the children in the sample failed to score at all), the accuracy data showed that children were able to complete at least one item of each subtest. This implies that the children were able to understand and perform the basic tasks of each subtest (Manly et al., 2001). Furthermore, 96 children from the sample also completed additional behavioral measures of attention and some of these standardized scores were available for comparison with the TEA-Ch subtests. From these correlations, several patterns support the categorization of attentional demands required for various subtests. The Map Mission and Sky Search subtests strongly correlated with the Stroop measure, which is typically considered to be a measure that demands selective attention (Manly et al., 2001). Furthermore, Map Mission and Sky Search, the only selective attention subtests on the TEA-Ch, were the only two tests to correlate strongly with the Stroop measure (Manly et al., 2001). They also examined whether or not a relationship existed between scores of the TEA-Ch and scores of conventional WISC-III IQ tasks. It was found that a significant relationship between the two does not exist, therefore supporting the focused nature of the TEA-Ch subtests and the value of having a separate assessment for functions of attention (Manly et al., 2001).

The TEA-Ch has also demonstrated strong discriminant validity and has been able to identify children with diagnosed attentional deficits compared to typically developing children. Since ADHD is becoming an increasingly common diagnosis among school-aged boys particularly, TEA-Ch scores of boys with a diagnosis of ADHD were compared to scores of boys from the normative sample. In a basic comparison, it was found that with the exemption of one of the subtests measuring selective attention, the two groups showed significantly different scores (Manly et al., 2001). However, upon closer inspection, the authors found that the boys with ADHD also had lower scores on tests that were unspecific to attention. After matching groups by age and scores on the WISC-III Block Design in order to produce a highly conservative comparison, it was found that boys with ADHD only had significantly lower scores in Score, Score DT, and Walk don't Walk, all sustained attention subtests.

While behavioral measures such as the TEA and the TEA-Ch are helpful in identifying an individual's ability to utilize selective attention, sustained attention, or control/shift attention, the assessments do not tell us much about the underlying brain processes that facilitate these types of attention. Electroencephalography, or EEG, on the other hand is able to provide a visual representation of brain activity.

Electroencephalography and Event Related Potentials

Electroencephalography, or EEG, is a method that is used to measure and record electrical activity in the brain. EEG is commonly used to examine processes such as sleep, attention, and emotion (Stern, Ray & Quigley, 2001). EEG can offer professionals, such as occupational therapists, with a means of understanding the underlying factors of problematic behavior that have negative implications for day to day activities. In order to obtain an EEG measurement, electrodes are strategically and systematically placed on the scalp in order to directly record cortical electrical brain activity. The 10-20 system is typically used to refer to the locations of these electrodes (Cole & Rugg, 1995). This system allows us to delineate where an electrode is placed on the scalp (Coles & Rugg, 1995). For example, the electrode placed at the central midline is labeled Cz, while the placement at the frontal midline is Fz, and at the parietal midline it is labeled Pz. However, the activity that is picked up at a particular location does not necessarily reflect the activity that is occurring directly below the scalp at that site. Rather, electrical activity is conducted throughout the brain and the precise origin of the activity cannot be determined from EEG alone (Cole & Rugg, 1995).

A summation of the activity that is picked up across the cortex of the brain establishes a spontaneous and continuous EEG waveform (Davies & Gavin, 2007; Stern et al., 2001). To examine the brain's response to a specific event, the brain activity recorded in the EEG can be time-locked to the onset of a stimulus. Since the voltage of brain activity related to a specific sensory stimulus is smaller than that of the spontaneous EEG, multiple trials are needed to establish a reliable pattern of the brain activity that is in response to a particular stimulus (Stern et al., 2001). By averaging these multiple sets of time-locked EEG measurements from multiple presentations of an identical stimulus over time, an Event Related Potential, or ERP is obtained (Segalowitz & Davies, 2004; Stern et al., 2001).

There are two types of measurements, or dependent variables, which can be used after acquiring an ERP. These measurements are known as amplitude and latency (Segalowitz & Davies, 2004). Amplitude refers to the magnitude of brain activity and is measured in microvolts, while latency refers to the temporal aspect of brain response and is measured in milliseconds (Davies & Gavin, 2007). In an ERP, there are positive and negative deflections over time. The positive deflections, labeled *P*, are those that peak above the baseline, while the negative deflections, labeled *N*, are those that peak below the baseline (Davies & Gavin, 2007). The number following either *P* or *N* in the component label is the approximate amount of time that the component occurred after onset of the stimulus in milliseconds. Since timing of each component is relative, it should be observed that in some cases a component, such as P200, may occur much later than 200 milliseconds after stimulus onset, yet it will always follow P100 and N200 (Stern et al., 2001). Additionally, these labels may be abbreviated so that N100 is also known as N1 and P200 is also P2 for example (Stern et al., 2001).

The amplitude of an ERP waveform component is commonly computed in two ways; from peak-to-peak or from baseline (Luck, 2005). Peak-to-peak amplitudes are determined by measuring the difference in amplitude between the peak in question and its preceding deflection of opposite polarity. With this method, the amplitude of P2 would be the difference in microvolts between the P2 peak and the N1 peak immediately prior (Luck, 2005). Finding the amplitude of a component using the baseline method can be complicated for time-locked ERP waveforms since the brain activity preceding the response to a stimulus is often similar to the response itself (Luck, 2005). There are two ways in which baseline can be calculated to solve this problem. One is to use a period of time far enough before the stimulus so that it always comes before the stimulus (Luck, 2005). Another way to calculate baseline is to average the entire epoch as baseline. The amplitude of each component is then found by measuring the maximum or minimum point of a peak from this baseline (Luck, 2005).

Many of the components that an ERP is composed of are believed to be associated with a specific cognitive function (Segalowitz & Davies, 2004). The components of particular importance to this study are N1 and N2, as they are two components thought to relate to attention.

N1

The N1 is one of the most easily identified ERP components (Key, Dove, and Maguire, 2005). With reasonable consistency in the literature, the N1 component is identified as being sensitive to attention. It has been found across a multitude of studies that the amplitude of N1 is larger for stimuli that are being attended to than for stimuli that are ignored (Hillyard, Hink, Schwent & Picton, 1973; Herrmann & Knight, 2001; Johnson, 1989). Using auditory stimuli, which will be used in this particular study, the N1 component is the earliest to reliably show changes in attention (Herrmann & Knight, 2001). In 1973, Hillyard, et al. conducted a study in which they presented a series of tones in each ear and asked participants to attend only to tones in one of the ears. The authors demonstrated that as early as 100 milliseconds post-stimulus, attention could influence the processing of a stimulus. This was the first definite evidence that N1 related specifically to selective attention (Hillyard et al., 1973). Comparing the results of a reaction time task to a simple counting task, Johnson (1989) found that auditory N1 is sensitive to attention based on difficulty level. More recently, Kisley et al. (2004) found that participants who attended more to irrelevant background sounds had larger N1 amplitudes, further establishing the relationship between N1 amplitude and attention.

Maturation of N1

Ponton, Eggermont, Kwong, and Don (2000) conducted a study measuring auditory evoked potentials (AEPs) to examine the maturation of several components including N1. The authors point out that any physiological changes identified in AEPs cannot be related to cochlear maturation or the auditory brainstem pathway since these functions have been demonstrated to be adult-like by birth and 2 years of age respectively (Eggermont, Brown, Ponton, Kimberley, 1996; Abdala & Siniger, 1996; Eggermont, 1988; Ponton, Eggermont, Coupland & Winkelaar, 1992). The authors assert that age-related changes seen in several ERP components are related to maturation that is taking place in at least some auditory perceptual skills (Ponton et al., 2000). The researchers examined differences in N1 amplitude and latency at multiple electrode sites in participants aged 5-20 years. The results of their study showed that using a passive listening task, different trends in N1 amplitude can be seen at various electrode sites (Ponton et al., 2000). The authors concluded that maturation of various ERP components cannot be adequately illustrated based on activity from a single electrode location. However, variability in peak N1 amplitude changes across age were similar for the Cz and Fz electrode sites. In general, the presence of N1 was inconsistent among participants until age 9 and N1 negativity became adult-like around age 16 in relation to baseline (Ponton et al., 2000). Overall, the findings of their study appear to suggest that N1 amplitude is smaller in children than in adults at the Cz and Fz sites using passive auditory paradigms.

N2

In comparison with N1, the N2 component appears to show more variation among individuals (Michalewski, Prasher & Starr, 1986). There is also increased discrepancy in the literature regarding the functional interpretation of the N2 component. Like N1, many researchers believe that the N2 component is related to attention (Satterfield et al., 1990; Duncan et al., 1994). In fact, for N2 to be present, a participant must be attending to stimuli (Key, Dove & Maguire, 2005). Distinctively how it is related to attention, however, is less certain. Some authors believe that N2 reflects task demands (Duncan et al., 1994), while others suggest it may relate to target selection (Donchin, Ritter & McCallum, 1978). Additionally, many researchers have proposed that N2 is associated with a discriminative process (Bernal et al., 2000; Satterfield et al., 1990; Loveless, 1983). Bernal et al. (2000) conducted a study in which they examined differences in N2 amplitude of typical children compared with children who were categorized as poor readers. The authors used an oddball paradigm in which participants were presented with frequent identical tones and a random infrequent tone. It was found that children who were considered poor readers displayed significantly larger N2 amplitudes for frequent tones yet significantly lower N2 amplitudes for the infrequent tones as compared to typical children. The authors believe that the results of their study suggest that the N2 component reflects effort to discriminate infrequent stimuli. The researchers further assert that typically developing children are able to discriminate infrequent stimuli more efficiently than poor readers because the poor readers are likely allocating more resources to stages prior to the cognitive function that is reflected by N2 (Bernal et al., 2000). Likewise, using visual stimuli, Paz-Caballero & García-Austt (1992) found that the N2 component was only elicited in discriminatory tasks. In this study, participants completed a task that required them to passively look at stimuli of differing geometric shapes and locations in addition to two tasks that required active response to certain stimuli. The study found that N2 was only elicited in discriminatory tasks and increased amplitude was related to target selection (Paz-Caballero & García-Austt1992).

Maturation of N2

The study conducted by Ponton et al. (2000) that is described above also examined the maturation of the N2 component using AEPs. In regards to the N2, an irregular but gradual decrease in amplitude could be seen at Cz and Fz sites with increasing age up to about 17 years. At this point, N2 amplitude became relatively consistent (Ponton et al., 2000). Overall, this leads to the conclusion that N2 amplitude is smaller in adults than in children. The maturation trends seen at various electrode sites may be due to the possibility that the N2 component is a function of multiple generators (Näätänen, Simpson & Loveless, 1982; Renault, Ragot, Lesevre & Redmond, 1982; Ritter, Simpson, Vaughan & Macht, 1982). The maturation trends may be reflective of the differing rates of maturation of those various generators (Ponton et al., 2000).

CHAPTER 2

Recent neurological and applied research is demonstrating that the definition of attention is more complex than a general state of arousal or concentration. Posner and Peterson (1990) first proposed that attention is composed of three interrelated but unique processes; orienting to sensory events, detecting signals for processing, and maintaining an alert state. Subsequent authors have also identified these three distinct subsystems, although the terms used to identify them may vary (Mirsky, Anthony, Duncan, Ahearn & Kellam, 1991; Robertson, Ward, Ridgeway & Nimmo-Smith, 1995). The Test of Everyday Attention for Children (TEA-Ch), used in the current study, utilizes the terms attentional control/shift, as the conscious shift or adjustment of attention to a particular target; selective attention, as the selection of a particular relevant target and inhibition of irrelevant stimuli; and sustained attention, as the continued processing of a particular target over time (Manly et al., 2001).

While behavioral measures such as the TEA-Ch are helpful in assessing one’s ability to utilize selective attention, sustained attention, or control/shift attention, the assessments do not tell us about the underlying brain processes facilitating these types of attention. Electroencephalography (EEG) and event-related potentials (ERP) however, are able to provide visual representations of brain activity while performing tasks that require different levels and types of attention.

Some ERP components are believed to be associated with a specific sensory or cognitive function (Polich, 1993; Segalowitz & Davies, 2004). In order to allocate meaning to these components, researchers have employed various EEG paradigms that are designed to place demands on specific cognitive systems. The sensory gating paradigm was originally developed to examine the brain’s ability to suppress repetitive auditory input (Erwin & Buchwald, 1986;

Davis, Mast, Yoshie & Zerlin, 1966; Roth & Kopell, 1969; Fruhstorfer, Soveri & Jarvilehto, 1970). The early gating mechanism, measured by the P50, was thought to be pre-attentive and later gating mechanisms, such as the N1, were thought to be under more attentional control. Recently several researchers have investigated the N1 and the role of attention in impacting gating (Jerger, Biggins & Fein, 1992; Guterman & Josiassen, 1994; Guterman, Josiassen & Bashore, 1992). Jerger et al. (1992) used a paradigm in which participants completed two separate tasks. In the first task, participants responded by lifting their pointer fingers to the sound of specific click intensity. In the second task, participants responded by lifting their pointer fingers when recognizing a pair of clicks rather than a single click. Both tasks included the same variety of paired verse single clicks and two different intensities. In task 1, participants were able to respond to the first click whereas task 2 required participants to wait for the second click before responding. The researchers examined the impact of this experimental manipulation on P50 and N1 amplitude. Results of that study showed that their experimental manipulation profoundly affected attention and these attentional effects were manifested in changes in N1 amplitude (Jerger et al., 1992).

In the current study, the sensory gating paradigm was uniquely adapted from the paradigm used in the Jerger et al. (1992) study. This was done so that the brain response thought to reveal the attentional manipulation could not be influenced by motor components related to finger movements, as was the situation in the Jerger et al. study. Rather than responding to either of the paired clicks, participants of the current study were only asked to respond to the single clicks in the focused attention task of the sensory gating paradigm. In doing this, we are able to examine how, specifically, the manipulation of attention impacts ERP components elicited in the sensory gating paradigm. By additionally comparing the impact of attention on ERP components to individual differences in behavioral attention scores on the TEA-Ch, we will be able to further validate the function of the examined components. Of particular importance to this study are N1 and N2, as they are thought to relate to attention.

N1 and N2 Components

The N1 is one of the most easily identified ERP components (Key, Dove, and Maguire, 2005). With reasonable consistency in the literature, amplitude of N1 has been shown to be sensitive to manipulations of attentional demands. It has been found across a multitude of studies that the amplitude of N1 is larger when stimuli are attended to than when ignored (e.g., Hillyard, Hink, Schwent & Picton, 1973; Herrmann & Knight, 2001; Johnson, 1989). Using auditory stimuli, as used in this study, the N1 component is the earliest to reliably show changes in attention (Herrmann & Knight, 2001).

In comparison with N1, the N2 component appears to show more variation among individuals (Michalewski, Prasher & Starr, 1986). There is also increased discrepancy in the literature regarding the functional interpretation of the N2 component. Like N1, many researchers believe that N2 is related to attention; for N2 to be present, a participant must be attending to stimuli (Satterfield et al., 1990; Duncan et al., 1994; Key, Dove & Maguire, 2005). Distinctively how it relates to attention is less certain. Some authors believe N2 reflects task demands (Duncan et al., 1994) while others suggest it relates to target selection (Donchin, Ritter & McCallum, 1978). Additionally, many researchers have proposed that N2 is associated with a discriminative process (Bernal et al., 2000; Satterfield et al., 1990; Loveless, 1983).

Maturation of N1 and N2

Ponton, Eggermont, Kwong, and Don (2000) conducted a study using a passive auditory task to examine maturation of several ERP components including N1 and N2. The authors assert that age-related changes seen in several components are related to maturation that is taking place in at least some auditory perceptual skills (Ponton et al., 2000). In general, the presence of N1 was inconsistent among participants until age 9 and N1 negativity became adult-like around age 16 (Ponton et al., 2000). Overall, their findings suggest that N1 amplitude is smaller in children than in adults at central and frontal sites during a passive auditory paradigm. Ponton et al. (2000) also examined maturation of N2 and noted that an irregular but gradual decrease in amplitude could be seen at central and frontal sites with increasing age up to about 17 years. At this point, N2 amplitude became relatively consistent (Ponton et al., 2000). Overall, this leads to the conclusion that N2 amplitude is smaller in adults than in children.

Purpose

The purpose of this project is to better understand individual differences found in behavioral measures of attention and in neurophysiological measures of attention elicited by two sensory gating paradigms differing in attentional demands. Additionally, we aim to examine if N1 and N2 represent different functional measures of attention. In doing this, three questions will be answered regarding attention in adults and children.

Question 1

How is the amplitude of N1 influenced by factors such as group and attentional demands?

Hypothesis 1.1. The N1 component will be larger in amplitude for adults than for children in both clicks across both paradigms.

Hypothesis 1.2. The N1 amplitude will be larger for both click 1 and click 2 in the focused attention paradigm compared to the sensory gating movie paradigm.

Question 2

How is the amplitude of N2 influenced by factors such as group and attentional demands?

Hypothesis 2.1. The N2 component will be larger in amplitude for children than for adults in both clicks across both paradigms.

Hypothesis 2.2. The N2 amplitude will be larger for both click 1 and click 2 in the focused attention paradigm compared to the sensory gating movie paradigm.

Question 3

Are individual differences in N1and N2 amplitudes reflected in individual performance on 3 dimensions of attention as measured by the TEA-Ch?

Hypothesis 3.1. Individual differences in attention scores on the TEA-Ch will be reflected in N1 amplitudes.

Hypothesis 3.2. Individual differences in attention scores on the TEA-Ch will be reflected in N2 amplitudes.

Methods

Participants

The study includes 23 healthy adults (12 females) between the ages of 20-30 years and 20 typically developing children (10 females) between the ages of 6-10 years. Participants with any reported physical, neurological, or behavioral disorders were excluded. Data for these participants were taken from a prior study that was funded by the National Institutes of Health (NIH) to Patricia L. Davies, PhD, Principal Investigator, R03 HD049532, “Sensory Gating Mediated by Attention.”

Adult participants gave informed consent. For child participants, parent permission and child assent was obtained. Children were recruited from the local northern Colorado community or parent contact if the child had participated in prior projects conducted in this lab and agreed to be contacted for future studies. Adults were recruited by posting flyers at the local University.

Behavioral Measures

Measures collected from the TEA-Ch are comprised of raw scores for each of the subtests grouped by the three subsystems of attention. The reason that we group the subtests by the subsystems of attention is because we intend to examine the relationship of N1 and N2 with the three types of attention. With the TEA-Ch being standardized up to age 16, in order to include adult data, raw scores rather than standard scores are used so that participants across all ages can be included. All items were administered and scored according to the standard procedures in the manual. The descriptions of the TEA-Ch subsystems are provided below.

Selective attention. The subtests included within this subsystem of attention are Sky Search and Map Mission. Both of these subtests require participants to identify and circle specific items among various sets of distractors. The purposes of these subtests are to demand that an individual utilizes his/her ability to select what is important to focus on and ignore the rest. In the Sky Search task, individual differences in motor speed are controlled for so that the final scores only reflect attention. Total attention score is time per target, calculated by subtracting the motor trial. In the Map Mission subtest, score is the number of correctly identified symbols in one minute.

Sustained attention. The subtests included within this subsystem are Score, Score Dual Task, Code Transmission, Walk Don't Walk, and Sky Search Dual Task. The purposes of each subtest within this system are to require participants to maintain their concentration for prolonged periods of time. Each test contains a relatively mundane and/or repetitive task that forces a participant to utilize their capacity for sustained attention. In subtests Score, Score Dual Task, Code Transmission, and Walk Don't Walk, the total score is the total number of targets correctly detected/reported. In the Sky Search Dual Task, the total score reflects time per target when completing Sky Search in conjunction with another counting task.

Attentional control/switching. The two subtests that assess a person's capacity for attentional control/switch are Creature Counting and Opposite Worlds. Each of these subtests requires a participant to switch their attention throughout the task; Creature Counting requires a switch between counting up and counting backwards while Opposite Worlds requires a switch between reporting exactly what is shown and reporting opposite of what is shown. Accuracy and speed are recorded in Creature Counting while the time difference between the two "worlds" is recorded for Opposite Worlds.

Electrophysiological Measures

In this study, ERP measures from two EEG paradigms were collected; sensory gating movie (SGM) and focused attention (FA). For both of these paradigms, participants were seated in a relaxed position with their eyes opened while quietly listening to auditory stimuli delivered binaurally through ER-3A insert earphones (Etymotic Research). The descriptions of conditions within the sensory gating paradigm used for this study are provided below.

Sensory gating movie (SGM) paradigm. For this paradigm, clicks were presented while the participant watched a silent animated movie. The purpose of this condition was to distract participants so that the auditory stimuli would remain unattended to. There were 104 pairs of clicks. Each click had a duration of 3 milliseconds and was presented at an intensity of about 70 decibels. The paired clicks had an interstimulus interval (ISI) of 500 milliseconds and 8 second inter-trial interval (ITI) between pairs.

Focused attention (FA) paradigm. In the focused attention paradigm adapted from Jerger, et al., 1992, clicks were presented while the participant stared at a fixed target on the computer screen. Each participant was instructed to press a button every time a single click was heard. The purpose of this condition was to present auditory stimuli to participants in a manner that the task required attention to the auditory stimuli. Within this condition there were 104 pairs of clicks and 54 single-clicks. The clicks were presented in four blocks lasting about 4 minutes with short breaks of 30 seconds to several minutes after each block. The clicks in this paradigm were the same intensity and duration as in the SGM paradigm. The paired clicks had an interstimulus interval (ISI) of 500 milliseconds and 8 second ITI between pairs or single clicks.

Procedures

This study reports data collected from a larger study. In the larger study, participants attended the Brainwaves Research Lab at Colorado State University for two visits. The second visit took place 1 to 2 weeks after the first visit at the same time and on the same day of the week as the first visit to control for confounding factors in performance. During each visit, the participants were involved in EEG testing for the first hour and behavioral testing for the second hour.

The EEG testing was completed with the participants in a relaxed seated position. After applying the electrode cap and prior to EEG recording, participants were provided with a short training period on how to reduce artifacts that can be produced by eye blink and muscle activity. All participants completed two EEG paradigms on each visit. On the first visit, the participants completed the sensory gating movie paradigm and a sensory registration paradigm. On the second visit, the participants completed the focused attention paradigm and the sensory gating movie paradigm, which were counterbalanced across participants. The EEG data collected on the second visit are the data reported here.

Following the EEG tasks and removal of the cap, participants completed the behavioral testing. During the behavioral testing portion of the first visit, all participants were administered the TEA-Ch. Auditory materials were presented through speakers connected to a portable laptop system. The behavioral tests administered on the second visit were not included in the data analysis for this study.

EEG/ERP Recording Method. A 32-channel BioSemi ActiveTwo EEG/ERP Acquisition System (BioSemi, WG-Plein 129, 1054 SC Amsterdam, Netherlands) was used to collect EEG Recordings. Recordings were made with an analog-to-digital sampling rate of 1024 Hz, a gain setting of 1000, and a bandwidth of 268 Hz. To control for activity related to eye movements, electrodes were placed on the left and right outer canthus for horizontal movements and on the left supraorbital and infraorbital region for vertical movements to record two bipolar electro-oculograms (EOG).

ERP Waveform and Component Analysis

EEG/ERP analyses were conducted offline using the Brain Vision Analyzer2 software (Brain Products GmbH, München, Germany). Recordings from the left and right earlobe were averaged and used as the offline reference. The four individual EOG channels were converted to a vertical and a horizontal bipolar EOG. A band pass of 0.23-30 Hz (12 dB/octave) were used for filtering the EEG recordings. Segmentation of the EEG included a 600 ms epoch with 200 ms pre-stimulus onset and 400 ms post-stimulus onset. Eye-blink artifacts were removed using a regression procedure. Segments that had deviations greater than ±100 µV on any other the EEG channels or the bipolar EOG channels were eliminated. The segments that were not rejected for each auditory stimulus were baseline corrected and averaged to create ERP waveforms for each participant.

Measures for peak-to-peak amplitude and latency for N1and N2 were obtained. We used visual inspection of the grand average to determine appropriate time windows for scoring specific components. N1 was identified between 70 and 150 ms and the peak-to-peak amplitude of this component was defined as the difference in μV between the N1 peak amplitude and the P1 (20-110 ms) peak amplitude. The N2 component was identified between 180 and 275 ms after the stimulus onset. The peak-to-peak amplitude of the N2 component was defined as the difference in μV between the N2 peak amplitude and the P2 (110-250 ms) peak amplitude. The peaks were scored at Fz, Pz, Cz, FC5, FC6, T7, and T8. The t-maps of differences between children and adults indicated that the greatest differences were at Cz site. Thus, the Cz site was used for statistical analysis of the amplitude and latency measurements for all components.

Data Analysis

In order to address the six hypotheses regarding the three research questions we proposed, ten statistical analyses were run. To answer research questions 1 and 2, a three factor 2x2x2 analysis of variance (ANOVA) was used with group (2 levels: adults and children) as a between subject factor, click (2 levels: click 1 and click 2) as a within factor, and paradigm (2 levels: SGM and FA) as a within factor. This test was run for two dependent variables, N1 and N2. Using *a priori* planned comparisons, the results of these tests will address hypotheses 1.1, 1.2, 2.1, and 2.2 (Kirk, 1968). In order to address hypotheses 3.1 and 3.2, eight regression analysis procedures were used to examine which attention scores from the TEA-Ch best predicted the N1 or N2 amplitude. All statistical analyses were performed using the Statistical Package for Social Sciences (SPSS) for Windows software, 19.0 version.

Results

Table 2 contains the means and standard deviations of N1 and N2 amplitude for adults and children in the focused attention and sensory gating movie paradigms across both clicks.

Table 2

N1 and N2 Amplitudes in Adults and Children Across Both Clicks and Both Paradigms

Paradigm	**N1 Amplitude M (SD)**		**N2 Amplitude M (SD)**	
Focused Attention	**Click 1**	**Click 2**	**Click 1**	**Click 2**
Adults	-14.60 (5.85)	-10.15 (2.74)	-12.59 (8.03)	-3.99 (2.25)
Children	-11.48 (6.36)	-7.92 (2.97)	-9.22 (9.47)	-5.52 (2.68)
Sensory Gating Movie				
Adults	-11.62 (5.98)	-6.02 (2.79)	-16.79 (11.61)	-6.40 (2.45)
Children	-9.13 (6.63)	-5.13 (2.48)	-8.79 (4.24)	-5.86 (3.67)

N1 Amplitude

As predicted in Hypothesis 1.1 and shown in Table 2, in the FA paradigm adults had larger N1 amplitudes than children for click 1. The same was true for click 2 in the FA paradigm. In the SGM paradigm, adults also had larger N1 amplitudes for click 1 and for click 2 compared to children. Results of the 3 factor ANOVA used to evaluate changes in N1 showed that the group main effect for N1 amplitude approached but did not reach significance, $F(1,36) = 3.211$, $p = .082$. *A priori* Tukey *t* tests were conducted to determine whether there were any significant differences between adults and children in the amplitude of N1 for either paradigm or click. Only click 1 in the FA paradigm showed that the adults (M = -14.60) had a significantly larger N1 amplitude compared to children (M = -11.48), t = -1.89, $p < .05$.

As predicted in Hypothesis 1.2 and shown in Table 2, adults and children had larger N1 amplitudes for click 1 in the FA paradigm as compared to the SGM paradigm. For click 2, adults and children also had larger N1 amplitudes in the FA paradigm as compared to the SGM paradigm. The paradigm main effect was significant, $F(1, 36) = 40.619$, $p < .0005$. *A priori*

Tukey *t* tests were conducted to determine whether there were any significant differences between the FA and SGM paradigms in the amplitude of N1 for adults and children across each click. All *a priori t* tests were significant. For children, the N1 amplitude was significantly larger in the FA paradigm (M = -11.48) compared to the SGM paradigm (M = -9.13) for click 1, t = -2.27, $p < .05$. N1 amplitude was also larger for children in the FA paradigm (M = -7.92) than in the SGM paradigm (M = -5.13) for click 2, t = -2.70, $p < .05$. Similar to children, the N1 amplitude was significantly larger for adults in the FA paradigm (M = -14.60) compared to the SGM paradigm (M = -11.62) for click 1, t = -3.38, $p < .05$. Finally, the N1 amplitude for adults was also significantly larger in the FA paradigm (M = -10.15) compared to the SGM paradigm (M = -6.02) for click 2, t = -4.69, $p < .05$.

Although we did not state predictions for N1 regarding gating, or decreases in amplitude from click 1 to click 2, the sensory gating paradigm that we used was originally designed to measure gating (Erwin & Buchwald, 1986; Davis et al., 1966; Roth & Kopell, 1969; Fruhstorfer et al., 1970). Based on previous literature, we would expect to see smaller amplitudes for the second click compared to the first click for both adults and children in both paradigms and we did find this to be true; the click main effect was significant, $F(1, 36) = 33.071$, $p < .0005$.

For N1 amplitude, none of the interaction effects were significant; the Paradigm x Group interaction effect was nonsignificant, $F(1,36) = 1.053$, $p = .312$ as were the Click x Group interaction effect, $F(1,36) = .657$, $p = .423$, the Paradigm x Click interaction effect, $F(1,36) = 1.035$, $p = .316$, and the Paradigm x Click x Group effect, $F(1,36) = .204$, $p = .654$.

The results of these analyses indicate that at the Cz site, the N1 amplitude was significantly larger for the FA paradigm as compared to the SGM paradigm for both adults and children. For both adults and children we also found that the amplitude of N1 is larger for click 1 than for click 2 across both paradigms. For click 1 in the FA task, adults had significantly larger N1 amplitude compared to the children.

N2 Amplitude

In regards to Hypothesis 2.1 and as shown in Table 2, in the FA paradigm adults had larger N2 amplitudes for click 1 as compared to children, which is opposite of our prediction that children would have larger N2 than adults. However, children did show a larger N2 for click 2 in the FA paradigm compared to adults. In the SGM paradigm, adults had larger N2 amplitudes for click 1 and click 2 compared to children. However, results of the 3 factor ANOVA revealed that the group main effect for N2 amplitude did not reach significance, $F(1,23) = 1.841$, $p = .188$. *A priori* Tukey *t* tests were conducted to determine whether there were significant differences between adults and children in the amplitude of N2 for either paradigm or click. Only for the SGM paradigm click 1 the adults (M = -16.79) had a significantly larger N2 amplitude compared to children (M = -8.79), t = 2.82, $p < .05$; again opposite of our prediction.

In regards to Hypothesis 2.2 and as shown in Table 2, adults had larger N2 amplitudes for click 1 in the SGM paradigm as compared to the FA paradigm. However, children showed a larger N2 for click 1 in the FA paradigm as compared to the SGM paradigm. For click 2, adults and children had larger N2 amplitudes in the SGM paradigm as compared to the FA paradigm. Results of the 3 factor ANOVA revealed that the paradigm main effect approached but did not reach significance, $F(1, 23) = 3.908$, $p = .060$. *A priori* Tukey *t* tests were conducted to determine whether there were any significant differences between the FA and SGM paradigms in the amplitude of N2 for adults and children across both clicks. N2 amplitude was only significantly larger for adults in the SGM paradigm (M = -16.79) compared to the FA paradigm

(M = -12.59) for click 1, t = -2.27, *p* < .05, and this finding was opposite of our prediction that N2 would be larger in the attention condition (FA).

Although we also did not state predictions regarding gating for N2, we did find that click 1 was larger in amplitude than click 2 for both adults and children across both paradigms. The click main effect was significant, *F*(1, 23) = 22.375, p < .0005. This is what we would have expected based on the literature (Erwin & Buchwald, 1986; Davis et al., 1966; Roth & Kopell, 1969; Fruhstorfer et al., 1970).

For N2 amplitude, there were significant interaction effects for Paradigm x Group, *F*(1,23) = 4.123, *p* = .054, and Click x Group, *F*(1,23) = 5.205, *p* = .032. The Paradigm x Click interaction effect was nonsignificant, *F*(1,23) = .135, *p* = .717, as was the Paradigm x Click x Group effect, *F*(1,23) = .836, *p* = .370.

The results of these analyses indicate that at the Cz site, adults showed a larger N2 amplitude in the SGM paradigm as compared to the FA paradigm for both clicks, which was opposite of our predictions. For children, this was only true for click 2. Only click 1 for children showed a larger N2 amplitude for the FA paradigm compared to the SGM paradigm; this was the only finding related to N2 that was in agreement with our prediction. For both adults and children we also found that the amplitude of N2 is larger for click 1 than for click 2 across both paradigms. For click 1 in the SGM paradigm, adults had significantly larger N1 amplitude compared to the children.

Attention Measures Predicting N1 and N2 evaluated using Regression

To address Question 3, regression analyses examining the relationship of N1 and N2 amplitudes with raw scores on the TEA-Ch were run. For each of the regression analyses the independent variables were entered in 4 steps, fixed in order. The first step was group (child and adult), the second step was selective attention subtest scores, the third step was sustained attention subtest scores, and the fourth step was control/switch attention subtest scores. These steps were included for each dependent variable. For both the SGM and FA paradigms there were 4 regression analyses, one for each dependent variable. For both paradigms, these dependent variables were amplitude of N1 for click 1, amplitude of N1 for click 2, amplitude of N2 for click 1, and amplitude of N2 for click 2, to make a total of 8 regression analyses.

Of the eight regression analyses that were run, only two showed significant results. The significant results of these two tests are the only results reported here. As seen in Table 3, for N1 amplitude in click 2 of the FA paradigm all steps were significant, meaning that subtest scores in all subsystems were significant predictors for N1 amplitude. Group itself was also a significant predictor, $R^2 = .180$, adjusted $R^2 = .157$, $F(1, 35) = 7.681$, $p = .009$. Adding selective attention subtest scores accounted for 3% variance more than group alone, $R^2 = .210$, adjusted $R^2 = .139$, $F(2, 33) = 2.932$, $p = .048$. Sustained attention scores accounted for 26.9% variance more than group and selective attention scores, $R^2 = .480$, adjusted $R^2 = .331$, $F(5, 28) = 3.226$, $p = .010$. Adding control/switch attention scores accounted for 12.4% more variance, $R^2 = .603$, adjusted $R^2 = .451$, $F(2, 26) = 3.952$, $p = .002$. The two specific subtests that best predicted N1 amplitude for click 2 in the FA paradigm were Sky Search, $\beta = .731$, $t = 2.336$, $p = .027$, and Creature Counting, $\beta = -.651$, $t = -2.824$, $p = .009$ (see Table 3).

Table 3

N1 Amplitude Predictor Click 2 in FA Paradigm

Step and Predictor Variable	**B**	**SE B**	**β**	**R²**	**Adjusted R²**	**R² Change**
Step 1				.180*	.157*	.180*
Constant	-10.022*	.557*				
Group	2.426*	.875*	.0424*			
Step 2				.210*	.139*	.030*
Constant	-9.539	5.084				
Group	.746	1.823	.130			
Sky Search	.492	.658	.234			
Map Mission	-.020	.059	-.119			
Step 3				.480*	.331*	.269*
Constant	-30.474*	11.900*				
Group	2.254	1.976	.394			
Sky Search	.867	.655	.413			
Map Mission	-.030	.055	-.179			
Score	.964	.514	.483			
Sky Search DT	-.002	.165	-.002			
Walk Don't Walk	.480*	.173*	.507*			
Score DT	-.349	.398	-.318			
Code Transmission	.260	.236	.263			
Step 4				.603*	.451*	.124*
Constant	-19.163	12.525				
Group	3.125	1.867	.546			
Sky Search	1.533*	.656*	.731*			
Map Mission	.012	.053	.069			
Score	.447	.500	.224			
Sky Search DT	.051	.152	.057			
Walk Don't Walk	.203	.206	.215			
Score DT	-.032	.378	-.029			
Code Transmission	.104	.227	.105			
Creature Counting	-2.080*	.737*	-.651*			
Opposite World	.018	.150	.026			

*$p < .05$

As seen in Table 4, of the four steps predicting N2 amplitude for click 1 of the FA paradigm, only the fourth was significant, $R^2 = .496$, adjusted $R^2 = .286$, $F(2, 24) = 2.361$, $p = .041$. Adding control/switch scores accounted for 26.1% variance more than just accounting for group and the other two types of attention. The three subtests that were the best predictors of N2 amplitude in click 1 were Code Transmission, β = .739, t = 2.498, $p = .020$, Creature Counting, β = .668, t = -2.479, $p = .021$, and Opposite Worlds, β = .612, t = 2.404, $p = .024$.

Table 4

N2 Amplitude Predictor Click 1 in FA Paradigm

Step and Predictor Variable	B	SE B	β	R^2	Adjusted R^2	R^2 Change
Step 1				.006	-.24	.006
Constant	-11.093*	1.897*				
Group	1.274	2.791	.079			
Step 2				.046	-.051	.036
Constant	6.047	16.343				
Group	-.278	5.828	-.017			
Sky Search	-1.836	2.100	-.309			
Map Mission	-.187	.190	-.403			
Step 3				.234	-.001	.193
Constant	-75.778	44.435				
Group	6.282	7.074	.391			
Sky Search	-.850	2.350	-.143			
Map Mission	-.093	.195	-.200			
Score	2.650	1.889	.477			
Sky Search DT	-.457	.574	-.184			
Walk Don’t Walk	-.661	.598	-.257			
Score DT	-1.518	1.435	-.494			
Code Transmission	2.233*	.899*	.805*			
Step 4				.496*	.286*	.261*
Constant	-67.539	44.184				
Group	11.014	6.160	.685			
Sky Search	-.310	2.156	-.052			
Map Mission	.107	.174	.230			
Score	.747	1.733	.134			
Sky Search DT	-.121	.494	-.049			
Walk Don’t Walk	-.871	.660	-.339			
Score DT	-.470	1.270	-.153			
Code Transmission	2.050*	.821*	.739*			
Creature Counting	-6.115*	2.466*	-.668*			
Opposite World	1.201*	.500*	.612*			

*$p < .05$

Discussion

In the current study, we employed the use of a functional assessment, the Test of Everyday Attention for Children, as well as two electrophysiological paradigms to examine attention in children and adults. The TEA-Ch allowed us to examine individuals’ abilities to utilize the three separate subsystems of attention proposed originally by Posner and Peterson

(1990). The focused attention and sensory gating movie paradigms allowed us to demonstrate the effects of manipulating the allocation of attention on N1 and N2 ERP components. Our purpose in this study was threefold. First, we aimed to determine if there were differences in N1 and N2 amplitudes between adults and children. Second, we wanted to find whether the manipulation of allocation of attention impacts N1 and N2 ERP components in adults and children. Third, we wanted to examine whether or not there was a relationship between ERP components, specifically N1 and N2, and any of the three attentional subsystems on the TEA-Ch.

In regards to our questions related to maturation, we found a trend for both N1 and N2 to show larger amplitudes in adults as compared to children across both clicks in both paradigms. We suspected, based on the literature, that adults would have larger N1 amplitudes for both clicks across both paradigms and the trends in our results were consistent with our hypotheses. For N1, predicted results were found where adults showed a significantly larger amplitude for click 1 in the FA paradigm compared to children. It is interesting that for N1, click 1 of the FA paradigm showed significant amplitude difference between adults and children because this is the only click in which there is a novel presentation of auditory stimuli that participants were required to actively focus on.

Based on the literature for the N2 component, we expected to see larger N2 amplitudes in children for both clicks across both paradigms, yet our findings suggest that there is actually a trend for adults to show larger N2 amplitudes (see Figure 1). A significant difference was found for click 1 of the SGM paradigm in which adults demonstrated a larger amplitude than children. Since N2 has been said to be reflective of discrimination tasks, a possible explanation for significantly increased N2 amplitude in adults for click 1 of the SGM paradigm might be that adults are better able to quickly register and dismiss an auditory stimuli that they determine is unimportant.

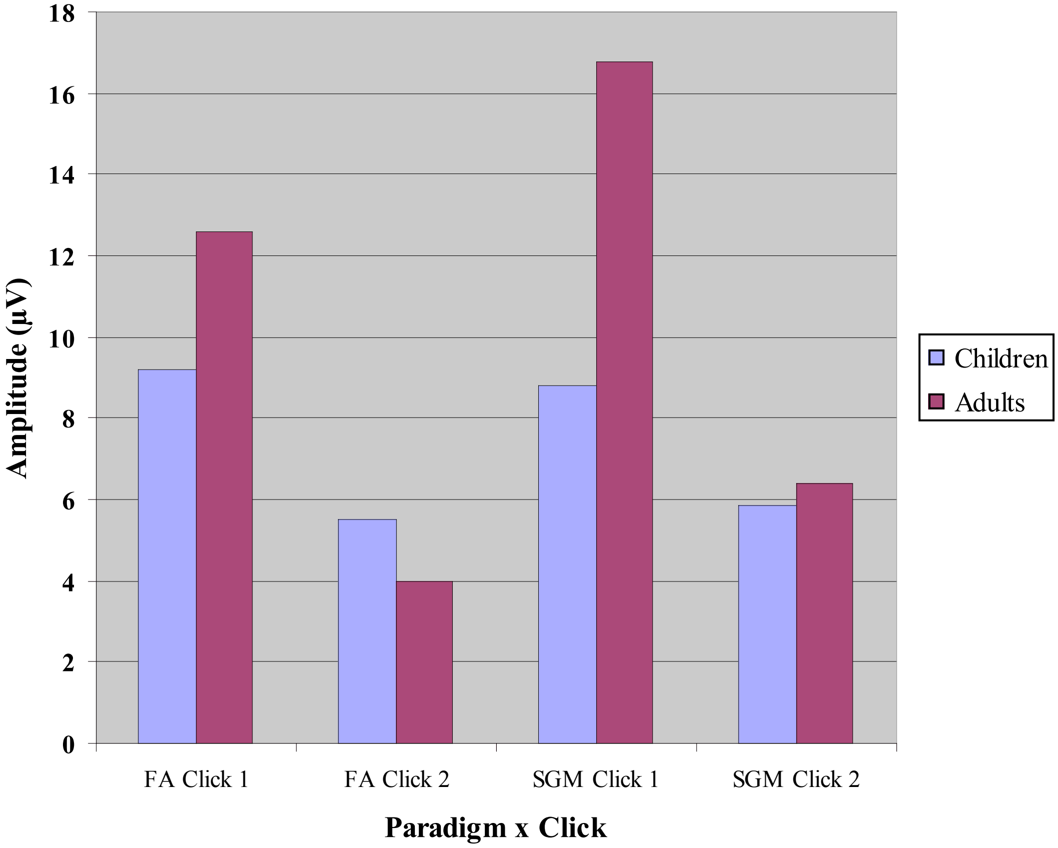

Figure 1. N2 amplitude differences across groups for click 1 and click 2 for both the FA paradigm and SGM paradigm.

To address the research questions regarding the effect of paradigm, we found that N1 amplitude was significantly larger in the FA paradigm than in the SGM paradigm. As expected, the increased attentional demands present in the FA paradigm were related to larger N1 amplitudes overall. This is consistent with the literature, suggesting that N1 amplitude is strongly related to attention (Hillyard, Hink, Schwent & Picton, 1973; Herrmann & Knight, 2001;

Johnson, 1989). The effect of paradigm on N2 amplitude came very close to also reaching significance. However, the direction of this finding was actually opposite of what we expected based on the literature. Rather than seeing larger N2 amplitudes in the FA paradigm, we actually found a trend for larger N2 amplitudes in the SGM paradigm, although the results were only significant for click 1 for adults (see Figure 2). Our possible explanation above, which states that N2 may be related to an individual's ability to register and dismiss information, also applies to why we may see a trend for larger N2 amplitudes in the paradigm that does not immediately demand attention to a task.

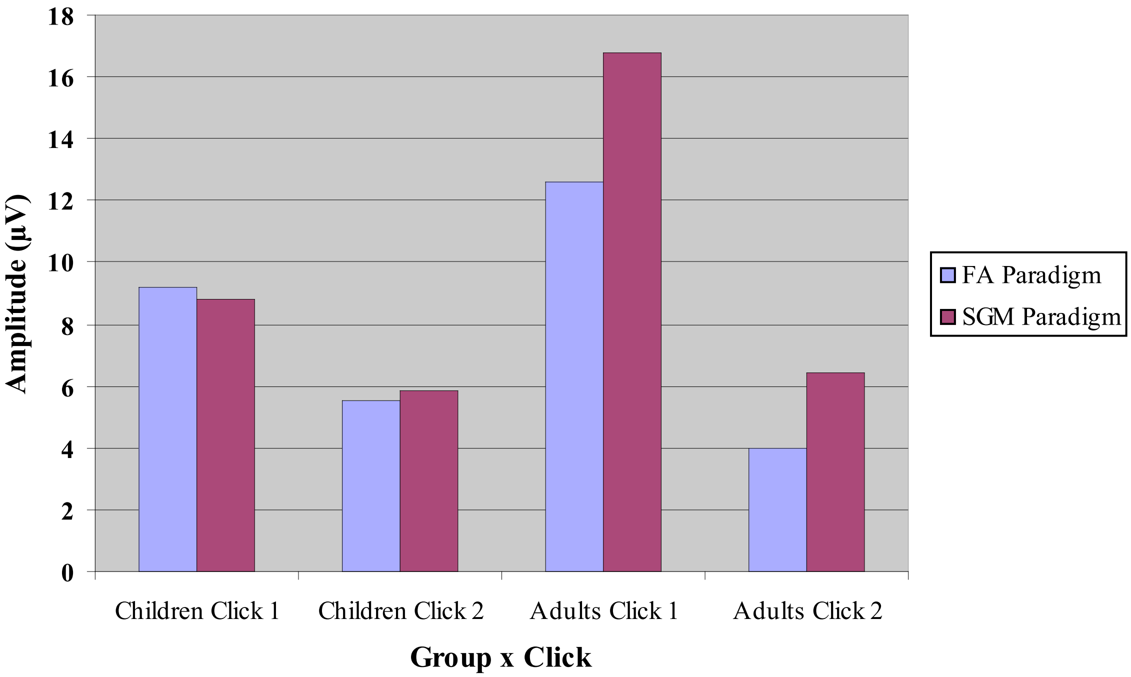

Figure 2. N2 amplitude differences across paradigms for click 1 and click 2 for both children and adults.

The manner in which the manipulation of the allocation of attention impacts N2 amplitude may be different for adults and children. Unlike N1, which saw similar patterns between the adults and children for each click across both paradigms, N2 amplitudes showed great variation in how the two groups responded. In Figure 2, it can be seen that N2 amplitude for children was very similar in the FA paradigm compared to the SGM paradigm for both of the clicks whereas adults clearly show higher amplitudes in the SGM paradigm. Additionally, as seen in Figure 3, the amplitude of N2 in children only shows minimal changes in response to the two clicks within each paradigm. This is also a stark difference from what we see with adults, who demonstrate significantly smaller amplitudes for the second click as compared to the first click in each paradigm. These differences between the two groups suggest that gating ability for N2 amplitude is much more advanced in adults compared to children. The effect of attentional manipulation on N2 is also more clear in adults than in children. In examining these data, it becomes clear why a group effect, which averages the N2 amplitudes for each group in each paradigm, failed to reveal the differences in N2 amplitude between the two groups.

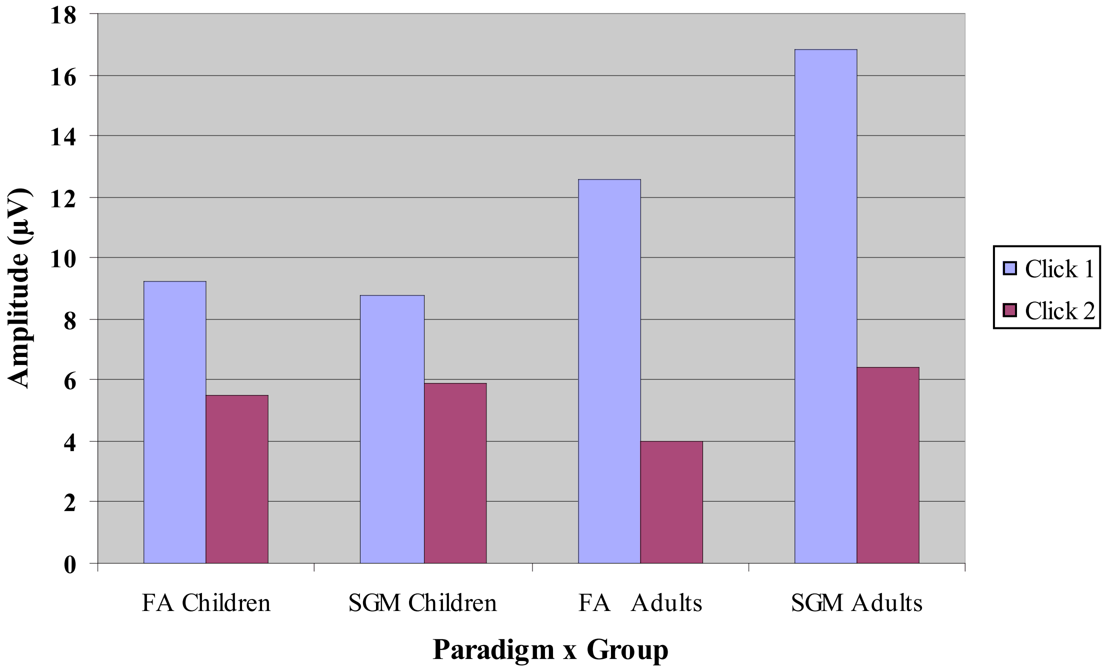

Figure 3. N2 amplitude differences across clicks for the FA paradigm and SGM paradigm for both children and adults.

In regards to our third research question, which asked how TEA-Ch scores related to N1 and N2 amplitudes, we found that both N1 and N2 amplitudes have at least one attentional subsystem that is a significant predictor in the FA paradigm. For N1 amplitude in click 2 of the FA paradigm, all 3 subsystems were significant predictors of N1 amplitude. Of all of the individual TEA-Ch subtests, the scores for Sky Search, a selective attention subtest, and Creature Counting, a control/switch attention subtest, were the strongest predictors of N1 amplitude in click 2 of the FA paradigm. These findings for N1 are in line with the literature in terms of this component's relationship to attention. Although none of the TEA-Ch scores were significant predictors of N1 amplitude in click 1 of the FA paradigm, we suspect that click 2 of the FA paradigm may have had more significant attentional demands. We believe that this is due to the fact that participants are required to listen for the second click before determining whether or not to make a response.

As seen with N1 amplitude, the FA paradigm was also the only paradigm in which we found significant TEA-Ch score predictors for N2 amplitude. Interestingly, we found that for N2 amplitude it was click 1 rather than click 2 that had any significant predictors. The only attentional subsystem that was a significant predictor of N2 amplitude in click 1 of the FA paradigm was control/switch attention. In examining which individual TEA-Ch subtests were the best predictors of this amplitude, we found that there were three; Code Transmission, a sustained attention subtest, Creature Counting, a control/switch attention subtest, and Opposite Worlds, a control/switch attention subtest. If N2 is in fact related to registering and quickly dismissing irrelevant stimuli as we theorized above, this may also explain why we found that control/switch attention subtest scores on the TEA-Ch were only reflective of N2 amplitude in the first click of the FA paradigm. Since we believe that click 2 of the FA paradigm may have the strongest attentional demands, participants may be quickly dismissing click 1 in preparation for making a decision related to click 2.

Overall, our findings related to the N1 component support the existing literature. The N1 component in our study was found to be larger in amplitude for the EEG paradigm in which there were higher attentional demands. This is consistent with findings from previous studies that have found larger N1 amplitudes for stimuli that are attended to as compared to stimuli that are ignored (Hillyard, Hink, Schwent & Picton, 1973; Herrmann & Knight, 2001; Johnson, 1989). The maturation of N1 is similarly consistent with the study conducted by Ponton et al. (2000) in which N1 amplitudes were found to be larger in adults than in children. Although our findings only revealed a significantly larger N1 in adults compared to children in click 1 of the FA paradigm, there was a trend for larger N1 amplitudes in adults across both clicks in both paradigms. Although there is discussion in the literature that N1 may relate to selective attention specifically, our findings revealed that a combination of the subtest scores from all subsystems was the strongest predictor. This may likely be due to the fact that selective attention as it is described in ERP literature may be comprised of additional abilities than what is defined as selective attention for the TEA-Ch. It is possible that N1 actually reflects a more global type of attention and therefore relates to all 3 subtypes of attention proposed by Posner and Peterson (1990).

Overall, our findings on the N2 component were much different than we had originally predicted based on the literature. Although existing literature has discussed the relationship of N2 to attention, we did not find N2 amplitude to be largest in the condition requiring more attention allocation (FA paradigm) with consistency. In fact, we found that there was a trend for larger N2 amplitudes in the condition that required no attention (SGM paradigm). We also failed to find significantly larger N2 amplitudes in children compared to adults. Instead we found that N2 amplitudes tended to be larger in adults compared to children. An interesting difference between adults and children in relation to the N2 amplitude was the gating pattern that we saw between each click in both paradigms. While adults demonstrated considerably larger amplitudes for click 1 compared to click two in both paradigms and for both ERP components, children did not show this pattern to the same degree. Children’s N1 gating pattern was similar to adults, yet their N2 gating pattern appeared less advanced. Additionally, adults showed larger amplitudes in the SMG paradigm as compared to the FA paradigm while children’s N2 amplitudes remained quite consistent between the two paradigms. So although our data was not consistent with the findings of Ponton et al. (2000) in terms of N2 maturation, we did find that there were distinct differences between the adults and children.

Due to our relatively small sample size, the results of our study would have benefitted from increased power and some of our findings may be impacted by type II error. Many of our data showed clear trends that approached but did not reach significance. We believe that with increased statistical power, it is likely that our results would have been much more conclusive. Another limitation of this study may be that the behavioral measure utilized in this study was standardized on children ages 6-16. Although we used raw scores for our analyses, it may be difficult to reliably reflect individual attentional differences using this method. Not all of the subtest scores reflected the same value, which also may have distorted our results related to the TEA-Ch.

Conclusion

Utilization of a behavioral assessment in addition to EEG paradigms that reflect ERP changes related to attention provided evidence for the relationship of N1 and N2 to attention as well as differences in N1 and N2 amplitude between adults and children. Regarding differences between ERP components in adults and children, there was a trend for larger N1 amplitudes in adults compared to children as expected, especially for click 1 in the FA paradigm. Alternatively from what was expected, N2 demonstrated a trend for larger amplitudes in adults compared to children and significantly so for click 1 in the SGM paradigm. In regards to ERP differences across paradigms, results showed that N1 amplitude was larger in the FA paradigm for both adults and children across both clicks as anticipated. N2 however, showed similar amplitudes for children across the two paradigms and actually showed larger amplitudes for the SGM paradigm for adults. Lastly, relating ERP components to scores from a behavioral attention measure showed that N1 seemed to relate to attention behaviors on subtests of all attentional subsystems on the TEA-Ch whereas N2 seemed only to relate to the control/switch attentional subsystem.

CHAPTER 3

An individual's capacity for attention has implications for many of life's activities. In order to successfully accomplish important tasks throughout the day, our minds must constantly go through the process of effectively disengaging our attention from one stimuli before orienting to a new one. Among all of the distractions in the environment, we must also be able to identify and process important input while simultaneously ignoring irrelevant stimuli. For many people with conditions such as Attention Deficit Hyperactivity Disorder (ADHD), an Autism Spectrum Disorder (ASD), or a Sensory Processing Disorder (SPD), there may be difficulties in carrying out these processes (Dunn & Bennett, 2002; Landry & Bryson, 2004).

Occupational therapists commonly receive referrals to address occupational performance issues that are impacted by these attentional difficulties. In recent years, occupational therapists have relied on the use of classroom adaptations such as stability balls and weighted vests to address issues related to sustained attention (Fedewa & Erwin, 2011; Collins & Dworkin, 2004; VandenBerg, 2001). Similarly, the use of assistive technology in and outside of the classroom has been found to be a helpful treatment tool (Robins, Dickerson, Stribling & Dautenhahn, 2004). Since attention is such a multidimensional process, it can often be difficult to pinpoint exactly where the problem lies. The attentional difficulties that are commonly seen in one diagnosis may be different from another diagnosis even though they are both associated with attentional deficits. Recognizing the various components that make up the concept of attention has begun to help us understand how attentional deficits manifest in individuals with various diagnoses. For example, Manly et al. (2001) found that boys with ADHD showed significantly lower scores on tests of sustained attention but were similar to typical boys on measures of selective and control/switch attention. Children with an ASD on the other hand have been reported to have difficulties transitioning or switching their attention from one task or stimuli to another (Landry & Bryson, 2004).

Assessments such as the Test of Everyday Attention for Children have been created to help distinguish which elements of attention may be contributing to problematic areas. Results of our study supported the idea that the TEA-Ch is able to identify separate but related attentional processes. Our data revealed that the three subsystems did not equally predict the amplitude of ERP components related to attention. If the subtest scores from each of the three attentional subsystems on the TEA-Ch were indistinguishable, it could be expected that they would each be similar predictors. Tools such as the TEA-Ch can therefore be helpful to occupational therapists during assessment of children who are referred for issues related to attention. This assessment can help identify what elements of attention are most difficult for a child and therefore what should be emphasized in treatment planning.

While behavioral measures are important for detailing the problematic outcomes of attentional deficits, they fail to fully inform us about the basic causes. Therefore, to understand the underlying mechanisms of these attentional components, it is helpful to relate a reliable behavioral measure such as the TEA-Ch to brain activity. As we begin to examine what is occurring within the brain, we can better recognize individual differences as well as how these abilities typically develop. This can therefore lead us towards a better understanding of the contributing factors for problematic behavior. Measures such as ERP may also be an additional method of aiding us in differentiating the types of difficulties that we see in various populations (Davies & Gavin, 2007). By understanding these differences at the neurological level, health care professionals are better equipped to plan treatment, predict outcomes, and provide more concrete answers to individuals and families impacted by these types of performance issues.

Additionally, measures such as EEG would be helpful in providing us with a means of tracking intervention outcomes in terms of changes from pre- to post-intervention (Gevensleben et al., 2009). Many of the strategies that professionals such as occupational therapists implement aim to change behavior (Fedewa & Erwin, 2011; Collins & Dworkin, 2004; VandenBerg, 2001). A treatment approach that intends to modify behavior assumes that the brain is plastic, yet minimal research exists that actually investigates this relationship (Gevensleben et al., 2009). Given the vast number of conditions that occupational therapists work with to directly address neurological dysfunctions that are negatively impacting occupational performance and participation, it is imperative that more studies with this focus be conducted. By examining the relationship between a measure of brain activity and a behavioral assessment related to a cognitive function such as attention, we help build better support for this assumption.

The results of this thesis found that certain ERP components are related to specific cognitive functions; in this case we related the N1 and N2 components to measures of attention. Our data also supported the idea that ERP components are different in adults compared to children in that the two groups do not always show the same neurological responses to a task. While we predicted that the N1 component would relate most specifically to selective attention subtests on the TEA-Ch, we actually found that all subsystems were a significant predictor of the component, suggesting that N1 represents a more global type of attention. N2 on the other hand was best predicted by control/switch attention subtests, suggesting that N2 is most related to an individual's ability to utilize control/switch attention. Overall, the results of this thesis have provided support for the multi-system nature of attention as well as the relationship of N1 and N2 ERP components to attention. The data have also highlighted the importance of examining neurological activity in order to advance our understanding of individual neurological differences and how these differences are reflected in the problematic behaviors that we identify.

REFERENCES

Abdala C, Sininger Y. (1996). The development of cochlear frequency resolution in the human auditory system. *Ear and Hearing, 17,* 374-385.

Bernal, J., Harmony, R., Rodríguez, M., Reyes, A., Yáñez, G., Fernández, T., Galán, L., Silva, J., Fernández-Bouzas, A., Rodríguez, H., Guerrero, V., Marosi, E. (2000). Auditory event-related potentials in poor readers. *International Journal of Psychophysiology, 36,* 11–23.

Coles, M. G., H. & Rugg, M. D. (1995). Event-related brain potentials: An introduction. In M.D. Rugg & M.G. H. Coles (Eds.), *Electrophysiology of mind: Event-related brain potentials and cognition* (pp. 1-26). London: Oxford University Press.

Collins, A. & Dworkin, R. J. (2011). Pilot study of effectiveness of weighted vests. *American Journal of Occupational Therapy, 65,* 688-694.

Davies, P. L. & Gavin, W. J. (2007). Validating the diagnosis of sensory processing disorders using EEG technology. *American Journal of Occupational Therapy, 61,* 176-189.

Davis, T., Mast, T., Yoshie, N. & Zerlin, S. (1966). The slow response of the human auditory cortex to auditory stimuli: Recovery cycle process. *Electroencephalography and Clinical Neurophysiology, 21,* 101-105.

Donchin, E., Ritter, W. & McCallum, W. C. (1978). Cognitive psychophysiology: The endogenous components of the ERP. In E. Calaway, P. Tueting & S. H. Koslow (Eds.), *Event-related potentials in man* (pp. 349–441). New York: Academic.

Duncan, C. C., Rumsey, J. M.,Wilkniss, S. M., Denckla, M. B., Hamburger, S. D. & Odou-Potkin, M. (1994). Developmental dyslexia and attention dysfunction in adults: Brain potential indices of information processing. *Psychophysiology, 31*, 386–401.

Dunn, W. & Bennett, D. (2002). Patterns of sensory processing in children with attention deficit hyperactivity disorder. *Occupational Therapy Journal of Research, 22,* 4-15.

Eggermont, J. J. (1988). On the rate of maturation of sensory evoked potentials. *Electroencephalography and Clinical Neurophysiology, 70,* 293-305.

Eggermont, J. J., Brown, D. K., Ponton, C. W., Kimberley, B. P. (1996). Comparison of distortion product otoacoustic emissions (DPOAE) and auditory brainstem response (ABR) traveling wave delay measurements suggests frequency-specific synapse maturation. *Ear and Hearing, 17,* 386-394.

Erwin, R. J. & Buchwald, J. S. (1986). Midlatency auditory evoked responses: Differential recovery cycle characteristics. *Electroencephalography and Clinical Neurophysiology, 64,* 417-423.

Fedewa, A. L. & Erwin, H. E. (2011). Stability balls and students with attention and hyperactivity concerns: Implications for on-task and in-seat behavior. *American Journal of Occupational Therapy, 65,* 393-399.

Fruhstorfer, H., Soveri, P. & Jarvilehto, T. (1970). Short-term habituation of the auditory evoked response in man. *Electroencephalography and Clinical Neurophysiology, 28,* 153-159.

Glevensleben, H., Holl, B., Albrecht, B., Vogel, C., Schlamp, D., Kratz, O., … Heinrich, H. (2009). Is neurofeedback an efficacious treatment for ADHD? A randomized controlled clinical trial. *The Journal of Child Psychology and Psychiatry, 50,* 780-789.

Guterman, Y. & Josiassen, R. C. (1994). Sensory gating deviance in schizophrenia in the context of task related effects. *International Journal of Psychophysiology, 18,* 1-12.

Guterman, Y., Josiassen, R. C. & Bashore, T. R. (1992). Attentional influence on the P50 component of the auditory event-related brain potential. *International Journal of Psychophysiology, 12,* 197-209.

Herrmann, C. S. & Knight, R. T. (2001). Mechanisms of human attention: Event-related potentials and oscillations. *Neuroscience & Biobehavioral Reviews, 25,* 465–476.

Hillyard, S. A., Hink, R. F., Schwent, V. L. & Picton, T. W. (1973). Electrical signs of selective attention in the human brain. *Science, 182,* 177–180.

Jerger, K., Biggins, C. & Fien, G. (1992). P50 suppression is not affected by attentional manipulations. *Biological Psychophysiology, 31,* 365-377.

Johnson, R. (1989). Developmental evidence for modality dependent P300 generators: A normative study. *Psychophysiology, 26,* 651–667.

Key, A.P. F., Dove, G. O., & Maguire, M. J. (2005) Linking brainwaves to the brain: An ERP primer. *Developmental Neuropsychology, 27,* 183-215.

Kirk, R. E. (1968). *Experimental design: Procedures for the behavioral sciences.* Belmont, CA: Brooks/Cole.

Kisley, M. A., Noecker, T. L. & Guinther, P. M. (2004). Comparison of sensory gating to mismatch negativity and self-reported perceptual phenomena in healthy adults. *Psychophysiology, 41,* 604-612.

Landry, R. & Bryson, S. E. (2004). Impaired disengagement of attention in young children with autism. *The Journal of Child Psychology and Psychiatry, 45,*1115-1122.

Loveless, N. E. (1983). *Event-related brain potentials and human performance*. In A. Gale & J. A. Edwards (Eds.), Physiological correlates of human behavior (pp. 79–97). London: Academic.

Luck, S. J. (2005). *An introduction to the event-related potential technique*. Cambridge, MA: Massachusetts Institute of Technology.

Manly, T., Nimmo-Smith, I., Watson, P., Anderson, V., Turner, A. & Robertson, I. H. (2001). The differential assessment of children's attention: The Test of Everyday Attention for Children (TEA-Ch), Normative sample and ADHD performance. *Journal of Child Psychology and Psychiatry, 42,* 1065-1087.

Michalewski, H. H., Prasher, D. K. & Starr, A. (1986). Latency variability and temporal interrelationship of the auditory event-related potentials (N1, P2, N2, and P3) in normal subjects. *Electroencephalography & Clinical Neurophysiology, 28,* 59–71.

Mirsky, A. F., Anthony, B. J., Duncan, C. C., Ahearn, M. B. & Kellam, S. G. (1991) Analysis of the elements of attention: A neuropsychological approach. *Neuropsychology Review, 2,*109-145.

Näätänen, R., Simpson, M. & Loveless, N. E. (1982). Stimulus deviance and evoked potentials. *Biological Psychology, 14,* 53-98.

Passantino, D. (2011). The test of everyday attention for children: A confirmatory factor analysis. (Master's thesis). Available from ProQuest Dissertations and Theses database. (UMI No. 1497996)

Paz-Caballero, M. D. & Garcia-Austt, E. (1992). ERP components related to stimulus selection processes. *Electroencephalography and Clinical Neurophysiology, 82,* 369-376.

Ponton, C., Eggermont, J., Kwong, B. & Don, M. (2000). Maturation of human central auditory system activity: Evidence from multi-channel evoked potentials. *Clinical Neurophysiology, 111,* 220-236.

Ponton, C. W., Eggermont, J. J., Coupland, S. G. & Winkelaar, R. (1992). Frequency specific maturation of the eighth nerve and brainstem auditory pathway: Evidence from derived auditory brain-stem response (ABRs). *Journal of the Acoustical Society of America, 91,* 1576-1586.

Posner, M. I. & Peterson, S. E. (1990). The attention system of the human brain. *Annual Review of Neuroscience, 13,* 25-42.

Renault, B., Ragot, R., Lesevre, N. & Redmond, A. (1982). Onset and offset of brain events as indices of mental chronometry. *Science, 215,* 1413-1415.

Ritter, W., Simson, R., Vaughan, Jr H .G. & Macht, M. (1982). Manipulation of event related potential manifestations of information processing stages. *Science, 218,* 909-911.

Robertson, I., Ward, T., Ridgeway, V. & Nimmo-Smith, I. (1996). The structure of normal human attention: The test of everyday attention. Journal of International *Neuropsychological Society, 2,* 525-534.

Robins, B., Dickerson, P., Stribling, P. & Dautenhahn, K. (2004). Robot-mediated joint attention in children with autism: A case study in robot-human interaction. *Interaction Studies, 5,* 161-198.

Roth, W. T. & Kopell, B. S. (1969). The auditory evoked response to repeated stimuli during a vigilance task. *Psychophysiology, 6,* 301-309.

Satterfield, J. H., Schell, A. M., Nicholas, T.W., Satterfield, B. T. & Freese, T.W. (1990). Ontogeny of selective attention effects on event-related potentials in attention-deficit hyperactivity disorder and normal boys. *Biological Psychiatry, 28,* 879–903.

Segalowiz, S. J. & Davies, P. L. (2004). Charting the maturation of the frontal lobe: An electrophysiological strategy. *Brain and Cognition, 55,* 116-133.

Stern, R.M., Ray, W. J. & Quigley, K.S. (2001). Brain: Electroencephalography and imaging. In R.M. Stern, W.J. Ray & K.S. Quigley (Eds). *Psychophysiological Recording* (2nd ed, pp. 79-105). New York: Oxford University Press.

VandenBerg, N. L. (2001). The use of a weighted vest to increase on-task behavior in children with attention difficulties. *American Journal of Occupational Therapy, 55,* 621-628.