THESIS

EVALUATING ATTENTION ALLOCATION IN CHILDREN TO YOUNG ADULTS WITH A SINGLE AND DUAL TASK EEG PARADIGM

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ABSTRACT

EVALUATING ATTENTION ALLOCATION IN CHILDREN TO YOUNG ADULTS WITH A SINGLE AND DUAL TASK EEG PARADIGM

Objectives. The ability to effectively allocate attentional resources between tasks has implications for participation in activities of daily living (ADLs) and instrumental activities of daily living (IADLs) across the lifespan. Neuroimaging techniques, such as electroencephalography (EEG) can measure cognitive processing with more precision than some behavioral paradigms and can evaluate the neural underpinnings of cognitive processes such as attention. Further, EEG has excellent temporal resolution, as it can measure changes in attention occurring at the neural level in milliseconds. This study's purpose is to understand how neural markers of attention are impacted in neurotypical participants under different task demands (i.e. single versus dual). This study also seeks to understand if attention is different across age under different task demands. Methods. All EEG data were collected for this study using a portable QuickTrace system (Neuroscan (Compumedics USA, 5015 West WT Harris Blvd, Suite E, Charlotte, NC 28269, USA)) from 29 scalp sites according to the 10-20 system. Data from 206 neurotypical participants age 7-25 (*M*= 13.64 years, *SD*= 4.21) were analyzed for this study. Each participant completed the novelty oddball paradigm (single task) and novelty dual task paradigm. Three distinct tone types (standard, target, and novel) are used in the novelty oddball (NOD) paradigm. Participants were instructed to press a button with their right index finger in response to the target tone. Participants were instructed to not respond to any other tones. In the novelty dual task (NDT) paradigm, participants continued to respond to target tone and simultaneously viewed numbers displayed on a computer monitor. Participants were instructed to press a button with their left index finger when there were three sequentially-presented odd numbers. Results. P3 amplitude and latency from Fz and Pz scalp sites during target tone presentation were analyzed. There was a negative correlation between participant age and P3 amplitude and latency at both Fz and Pz. There was no main effect of task nor an interaction of task and age on either P3 amplitude or latency at Pz. However, there was a significant main effect of task on P3 amplitude at Fz, as single task amplitudes were smaller than dual task amplitudes. There was also a significant interaction of task and age for P3 amplitude at Fz, demonstrating that the P3 amplitude in response to dual tasks decreased more with increasing participant age than P3 amplitude in response to single tasks. A significant interaction of task and age for latency at Fz was found, demonstrating that the latency of the P3 in response to single tasks decreases more with increasing participant age than the latency in response to dual tasks. Conclusions. These findings suggest that attention changes with age and that dual tasks are more effortful in younger participants compared to older participants. Future directions of this research include exploration of how manipulating the probability of hearing each stimulus affects amplitude and latency of the P3 in a three-tone novelty paradigm. Other future directions include exploration of the effects of differing task demands in populations such as those who may have attention deficits.

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CHAPTER 1 INTRODUCTION

Topic of Interest

Activities of daily living (ADLs) are defined as “activities oriented toward taking care of one’s own body” (AOTA, 2014, p. S19), while instrumental activities of daily living (IADLs) are defined as “activities to support daily life within the home and community that often require more complex interactions than those used in ADLs” (AOTA, 2014, p. S19). The ability to effectively allocate attentional resources has implications for both ADLs and IADLs that require multi-tasking, such as community mobility, social engagement, walking, play, leisure, grooming, and bathing (McDowd, Filion, Pohl, Richards, & Stiers, 2003; Melzer & Oddsson, 2004; Rahman et al., 2018). The types of ADL and IADLs in which an individual participates can vary significantly across the lifespan (Law, 2002), but an impaired ability to effectively allocate attention has the potential to impact participation at any age.

The load theory of attention suggests attention has limited capacity (Lavie, 2005). For example, performance of dual tasks (i.e. multitasking) versus single tasks is likely impacted by the limited capacity of attention. When an individual performs a single task, he or she can likely allocate all attentional resources to that activity. However, when engaged in two tasks, attentional resources must be divided - thus, reducing the amount of attention available for each task (Lavie, 2005). Lavie (2005) also found that more complicated tasks require more attention, which decreases or eliminates the amount of excess attention available for less complex or relevant tasks. If an individual sustains an injury or has a disease that affects executive function - which includes attention - he or she may have impaired performance on everyday occupations that require attention. In the case of injury or disease, less complex tasks would likely use all available attentional resources, and less attention would be available for multitasking. Therefore, performing a multistep task, such as cooking, would be more challenging, and it might be difficult or impossible to do another task, such as simultaneously have a conversation. As tasks become more complicated, task performance may suffer, induce frustration, or pose risk for injury.

Neuroimaging techniques, such as electroencephalography (EEG) can measure cognitive processing with more precision than some behavioral paradigms and can evaluate the neural underpinnings of cognitive processes such as attention. EEG has excellent temporal resolution and can measure the electrical activity occurring within the brain. An event-related potential (ERP) is a segment of EEG data that is time-locked to the presentation of a stimulus or response. ERPs are commonly used to study executive functions such as attention as they are more sensitive to cognitive deficits and changes than behavioral measures alone (Polich, 1993). The current study will use EEG to explore attention allocation under different task demands and as a function of age in participants 7 to 25 years old. The purpose of this study is to describe brain activity across age and task demand in neurotypical individuals. These findings can then be used to explore links between attention allocation and occupational performance limitations in clinical populations of individuals with attention deficits.

Introduction

EEG Background

Electroencephalography (EEG) is a non-invasive neuroimaging technique that measures the electrical activity of cortical structures (Banaschewski & Brandeis, 2007; Stern, Ray, & Quigley, 2001). EEG recordings are obtained by placing electrodes on the scalp, typically according to the International 10-20 system of electrode placement (Coles & Rugg, 1995; Klem, Lüders, Jasper & Elger, 1999) and represents a pattern of voltage variation across the scalp over time (Coles & Rugg, 1995). EEG recordings have excellent temporal resolution as they measure electrical activity in the brain in real time, while other techniques such as functional magnetic resonance imagery (fMRI) have low temporal resolution, as they often rely on hemodynamic responses to neural activity (Banaschewski & Brandeis, 2007; Horovitz, Skudlarski & Gore, 2002). Real-time fluctuations in EEG recordings can give insight into cognitive processes such as memory, arousal, consciousness, sleep, attention, emotion, and preparation for movement (Stern et al., 2001). Another advantage of EEG is that it can be used safely and relatively easily across all ages. EEG is useful for studying infants or children who are unable to focus, as EEG can be used when participants are not paying attention, attending to task-irrelevant stimuli, or even asleep (Banaschewski & Brandeis, 2007). For these reasons, EEG is an optimal technique for measuring real-time changes in attention allocation from childhood to adulthood.

ERP Background

An event-related potential (ERP) is a measured brain response that is time-locked to the presentation of a particular stimulus or a response (Coles & Rugg, 1995). ERPs are typically averaged across a series of trials (i.e. single stimulus and response) to produce a single average ERP. Averaging serves to eliminate additional brain activity that are not explicitly linked to the study paradigm (Coles & Rugg, 1995). The stimuli used to elicit an ERP can be visual, auditory, somatic, etc. in nature (Stern et al., 2001). Because ERPs are related to environmental events, they help define the brain's response to specific stimuli and events (Coles & Rugg, 1995; Stern et al., 2001). Because of the diverse practical applications of linking behavior and real-time changes in cortical activity, ERPs can be used to observe sensory and cognitive brain processes in both neurotypical and clinical populations.

An ERP is comprised of several different components, named after the relative amount of time, or *latency*, post-stimulus that the component is observed. Positive and negative deflections, or *amplitude* of the waveform are denoted with a 'P' or an 'N' when naming the component. For example, the component of interest in this study is a positive deflection typically occurring approximately 300 milliseconds after the stimulus onset, named the P300, or the P3. Earlier deflections observed in an ERP waveform (0-250 ms) reflect early sensory processing of the stimulus, including target detection (Coles & Rugg; Polich, 1993). Later ERP components reflect cognitive processes such as attention allocation and working memory updating (Stern et al., 2001; Polich, 2007). The P3 component has been said to index attention allocation (Polich, 2007) and can be used to measure how attention allocation develops across the lifespan. Therefore, the P3 component of the ERP will be the focus of the current study.

P3 Component and Cognitive Processes

The P3 component of an ERP typically occurs 300 milliseconds after the presentation of a stimulus. The P3 has been analyzed by some researchers as two separate components; the P3a and P3b. The two components differ in latency and neural generators suggesting reflection of different cognitive processes. The P3a typically occurs earlier and is generated in frontal-central regions of the brain, as opposed to the P3b which is generated in the parietal area of the brain (Bledowski, Prvulovic, Goebel, Zanella & Linden, 2004, Snyder & Hillyard, 1976; Squires, Squires, & Hillyard, 1975). The separation of the P3a and P3b waveforms according to their different latencies and neural generators is depicted in Figure 1. The separation of these two components in current literature is a result of many years of debate regarding what cognitive processes the P3 represents. Historically, researchers argued the P3 represented working memory updating. It was hypothesized that the component is produced when the mental representation of a stimulus is changed in response to an unexpected stimulus, and therefore requires updating (Donchin, 1981; Polich, 1993). For example, if a participant were presented with auditory tones, and a tone of particular frequency or loudness was expected, but another tone was unexpectedly presented, the mental representation of the tone held in the participant's working memory would require updating. Other authors refuted this theory, arguing there is little experimental evidence demonstrating the P3 occurs in response to unexpected stimuli (Verleger, 1988; Verleger, Jasowski, & Wacher, 2005).

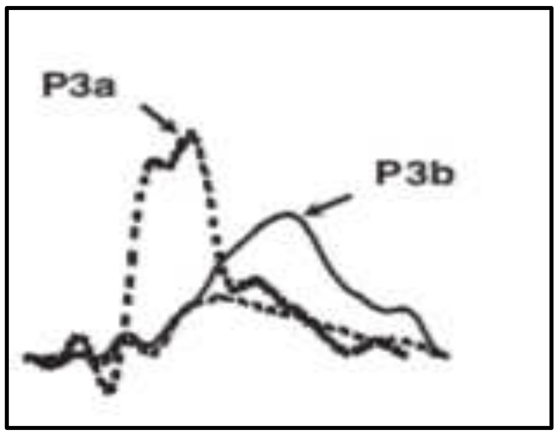

Figure 1: The P3a and P3b as elicited in a three-stimulus paradigm increasing in amplitude beginning from frontal generators to parietal generators (Polich & Criado, 2006, p. 173).

As a potential explanation for this dispute, Polich (2007) argued that in order to properly understand the cognitive processes the P3 represents, both the P3a and P3b need to be analyzed separately. Polich (2007) agreed that the P3 represents an update in working memory and concludes that this process is reflected in the P3b component. The P3b has a longer latency than the P3a (See Figure 1), a phenomenon that presumably reflects the increased processing time required to evaluate and discriminate incoming stimuli (Fjell, Rosquist, & Walhovd, 2009; Kutas, McCarthy, & Donchin, 1977). The P3a has been found to be elicited by novel, or task-irrelevant stimuli, while the P3b increases in amplitude in response to a stimulus that is targeted in a specific task (Knight, 1984; Strobel et al., 2008; Volpe et al., 2007; Wronka, Kaiser, & Coenen, 2008). Subsequently, the P3a reflects an orienting response to unexpected, task irrelevant (i.e. novel) stimuli (Escera, Alho, Schröger, & Winkler, 2000; Friedman, Cycowicz, & Gaeta, 2001; Ritter, Vaughan, & Costa, 1968; Roth & Kopell, 1973; Yamaguchi & Knight, 1991), while the P3b reflects voluntary attention allocation and subsequent working memory updating of task-relevant (i.e. target) stimuli (Coles & Rugg, 1995; Polich, 2007; Polich & Criado, 2006; Yamaguchi & Knight, 1991). Many studies of clinical populations (Jacobs, Dykens, & Key, 2018; Lasaponara et al., 2018; Mannarelli et al., 2018; Molina et al., 2018; Sokhadze et al., 2017) and neurotypical populations (Bledowski et al., 2004, Strobel et al., 2008; Volpe et al., 2007) have used the P3 to evaluate cognitive processing and consistently define the P3a as a representation of involuntary attention allocation to novelty and task-irrelevant stimuli, and the P3b as a representation of voluntary stimulus evaluation and memory updating.

This section has described the distinction between the P3a and P3b. In this thesis, the acronym ‘P3’ will he used to describe the general concept of the P3. When referring to one of the two separate components of the P3, acronyms “P3a’ or ‘P3b’will be used.

Cognitive Processes Associated with Latency and Amplitude of the P3

The latency of a component is measured in milliseconds and is calculated by the amount of time that elapses from stimulus onset to neural response. P3 latency is thought to reflect stimulus processing time (Coles & Rugg, 1995; Kutas et al., 1977; Magliero, Bashore, Coles, & Donchin, 1984) and can be impacted by age, diagnosis, and task demands (Polich, 2007; Tsai, Hung, & Lu, 2012; Wronka et al., 2008; Zenker & Barajas, 1999). The amplitude of a component is measured in microvolts and reflects change in voltage from baseline (i.e. baseline-to-peak measurement) or the preceding peak (i.e. peak-to-peak measurement). The amplitude of the P3 component reflects the degree of cognitive processes - specifically, attention and working memory updating - that are allocated in response to a stimulus (Polich, 2007). Therefore, a larger P3 amplitude would represent a greater degree of attention allocation in response to a given stimulus.

Auditory Oddball Paradigm

It is well documented that the P3 component of the ERP can be elicited with an oddball paradigm (Fuchigami et al., 2009; Gray, Ambady, Lowenthal, & Deldin, 2004; Horovitz et al., 2002; Kilpeläinen et al., 1999; Polich, 2007; Volpe et al., 2007; Wilson, Harkrider, & King, 2012; Zenker & Barajas, 1999). The classic auditory oddball paradigm involves repetition of the same tone - deemed the 'standard tone' - with periodic presentations of a tone of a different frequency - deemed the 'target tone' (Polich, 1993). An active paradigm requires the participant to engage in a behavioral response upon hearing the target tone, such as pressing a button, while a passive paradigm does not require a behavioral response. As an example, Wronka and colleagues (2008) evaluated attention allocation, via P3 amplitude, in a passive versus active auditory oddball task in neurotypical adults. In the active condition, participants were asked to count the number of deviant (i.e. oddball) auditory stimuli in their head. In the passive condition, participants were told to ignore the auditory stimuli and to count the number of female or male faces presented in a separate visual task. They found that P3 amplitudes were larger in the active condition, suggesting that the active condition elicited greater attention allocation to the auditory stimuli.

The novelty oddball is another experimental paradigm used to study cognitive processes and further elucidate the differences between P3a and P3b components. In this paradigm, a third tone, deemed a 'novel tone' is inserted into the classic auditory oddball paradigm and is presented at a probability less than or equal to that of the target tone (Friedman et al., 2001). This tone does not require a behavioral response and is meant to be ignored by the participant. Nonetheless, P3a amplitude is larger in response to the novel tone compared to the standard tone. (Knight, 1984; Strobel et al., 2008; Volpe et al., 2007; Wronka et al., 2008). This increased amplitude likely reflects the orienting response, or involuntary attention allocation, to the unexpected tone, despite the tone not requiring a behavioral response (Friedman et al., 2001; Yamaguchi & Knight, 1991). Both the classic auditory oddball and novelty oddball paradigm can be used to compare groups to evaluate differences in cognitive processes between participants of varying ages or diagnoses.

Developmental Trends of the P3

Examining age differences in P3 amplitude and latency can highlight maturational cognitive changes (Curry & Polich, 1992). Because the P3 reflects attention and working memory updating, it is a useful tool for determining how these processes change during childhood and adolescence. For example, Kilpeläinen and colleagues (1999) explored the development of the P3 from childhood to adulthood in healthy participants 9-32 years old using an active auditory oddball paradigm. They found that P3 latency was significantly longer and P3 amplitude was significantly smaller in children compared to adults. Additionally, research using the auditory oddball paradigm has demonstrated that P3 latency decreases with age until a plateau at puberty (Curry & Polich, 1992; Fuchigami et al., 1995; Fuchigami et al., 2009; Kilpeläinen et al., 1999; Mahajan & McAurthur, 2015). These findings reflect the maturation of cognitive processing from childhood to adulthood (Courchesne, 1978; Mahajan & McAurthur, 2015, Overbye, Huster, Walhovd, Fjell, & Tamnes, 2018).

Van Dinteren, Arns, Jongsma, and Kessels (2014a) used an auditory oddball paradigm to study neurotypical participants aged 6-87. They found that the amplitude of the parietal P3 tends to increase during childhood with a maximum around 21 years old followed by a slow decrease throughout adulthood. They also found that the amplitude of the frontal P3 reaches a maximum much later around 46 years old, with much less age-related decline (Van Dinteren et al., 2014a). According to Overby and colleagues (2018), these differences likely reflect the different roles of the P3a and P3b given their different neural generators. Work by Van Dinteren and colleagues (2014a) adds to the growing body of evidence regarding age-related changes that effect the P3 and demonstrates the value of studying the P3a and P3b separately given their different developmental trajectories.

Single vs. Dual Task Auditory Oddball

Importantly, past work that explored age effects on P3 amplitude and latency used a classic auditory oddball paradigm in a single task design. According to Wilson and colleagues (2012), there is limited research exploring how varying task demands affect P3 amplitude and latency. Further, there is limited research exploring task demand and age interaction effects with a novelty oddball paradigm. Such data has the potential to further describe attention allocation in neurotypical subjects which could then be used to evaluate attentional allocation abnormalities in clinical populations.

Some researchers suggest that adding a distractor task to the classic auditory oddball paradigm can make it more sensitive to deficits in cognitive functioning (Wilson et al., 2012). A study by Wilson and colleagues (2012) used an increasingly complex visual distractor during an auditory oddball paradigm to evaluate how increasing task demands affected P3 amplitude in neurotypical adults. They found the P3 amplitude was largest in a simple passive condition and decreased when more complex distractors that required active attention were added. This suggests attentional resources available for other tasks decrease with more complex distractors, potentially disrupting performance. This study also demonstrates that actively engaging in two tasks at once uses more attentional resources than only participating in one active task.

Jocoy, Arruda, Esttes, Yago, and Coburn (1998) evaluated how task demands affected the P3 amplitude in neurotypical teenaged participants. The single task consisted of an auditory oddball task, while the dual task required the participant to engage in the auditory oddball task and a visual memory task. They found that the P3 amplitude was largest in the single task paradigm and decreased when a visual distractor was added into the paradigm. These results were found at all three central sites (Fz, Cz, and Pz).

Finally, a similar result was found in participants who had sustained a sports-related concussion or had participated in contact sports (Wilson, Harkrider, & King, 2014). Wilson and colleagues found that participants who played contact sports either with or without a diagnosis of a concussion had lower P3b amplitudes when asked to actively attend to a visual distractor compared to the control group. These results suggest that concussions and sub-concussive blows can affect attention allocation. These studies demonstrate that when task demands increase, P3 amplitudes to target stimuli decrease. This indicates that- in neurotypical adults and teenagers- distractor tasks pull attention resources away from target stimuli. Manipulating task demands can also elucidate deficits in attention in populations like youth with concussion or sub-concussive exposure. However, to date, no one has evaluated the combined effect of age and task demands on P3 amplitude and latency in a large neurotypical cohort.

Purpose

The purpose of this study is to address the gaps identified in the P3 literature. Currently these gaps include a limited understanding of how age and task demands affect P3 latency and amplitude in neurotypical participants. While age-related differences in P3 amplitude and latency have been established, these developmental trends have not been evaluated with a novelty oddball paradigm or in conjunction with varying task demands. Studies exploring scalp topography data and EEG have found that attention allocation to task-relevant stimuli results in a P3 reaching its maximum in the parietal region, while attention allocation to task-irrelevant stimuli results in a P3 reaching its maximum in the frontal region (Horovitz et al., 2002; Overbye et al., 2018; Volpe et al., 2007). Our focus is on attention allocation to task-relevant stimuli, and based on previous literature, this type of attention allocation is generated in the parietal region of the brain. It is therefore assumed that attention allocation to task-relevant stimuli will yield significant activation at Pz, the EEG electrode centered over the parietal region of the brain. However, to date no other research has been done on a large neurotypical cohort with a wide range of participant ages using a three-tone oddball paradigm while also manipulating task demands. Therefore, to gather a complete picture of attention allocation in this paradigm, all analyses were also conducted at Fz, or the electrode centered over the frontal region of the brain. Given the emphasis in previous literature on the frontal and parietal regions related to attention allocation (Ptak, 2011), Fz an Pz were the scalp sites chosen for analysis. These data can be used in future studies with clinical populations to potentially explore the link between attention allocation and risk for injury or occupational performance limitations.

CHAPTER 2 METHODS AND RESULTS

Research Questions and Hypotheses

Development of the P3

Does the P3 component of an ERP change across age groups in amplitude and latency at Fz and Pz in response to the target tone?

Hypothesis 1a

The amplitude of the P3 at Fz and Pz will increase significantly with age in both single and dual task paradigms.

Hypothesis 1b

The latency of the P3 at Fz and Pz will decrease significantly with age in both single and dual task paradigms.

Single Versus Dual Task

Is P3 amplitude and latency different at Fz and Pz in response to the target tone when a participant is responding to auditory stimuli (i.e. single task) compared to responding to a auditory *and* visual stimuli (i.e. dual task)?

Hypothesis 2a

When controlling for age, the amplitude of the P3 at Fz and Pz will be significantly larger when the participant is engaged in a single task compared to a dual task.

Hypothesis 2b

When controlling for age, the latency of the P3 at Fz and Pz will be significantly shorter when the participant is engaged in a single task compared to a dual task.

Attention and Age

Is there an interaction of age and task demands on the P3 at Fz and Pz in response to the target tone?

Hypothesis 3a

During dual tasks, children will have significantly smaller P3 amplitudes at Fz and Pz than adults.

Hypothesis 3b

During dual tasks, children will have significantly longer P3 latencies at Fz and Pz than adults.

Exploratory Question

What is the effect of age and task on amplitude and latency at Pz and Fz in response to novel tones?

Methods

Participants

Data were collected from 277 participants age 7-25. Participants were recruited from the local community through presentations at community schools and youth organizations. All participants provided informed consent prior to participation in the experiment. No event markers were recorded in the raw EEG files for the first 60 participants due to a technical error, so we could not use EEG data for these participants. Additionally, only neurotypical participants were included in the analysis. Two participants were excluded due to depression, one participant was excluded due to a previous head injury, one participant was excluded due to a reading disability, and one participant was excluded as he had taken medicine in the morning. Finally, 6 participants had viable single task data but did not have viable dual task data, so they were excluded from analyses. Therefore, data from 206 participants age 7-25 (*M*= 13.64 years, *SD*= 4.21) were analyzed for the current study (see Table 1 for age and sex breakdown).

Table 1: Number of participants by Age category and Sex (total N = 206).

Participant Age Group	# Males / # Females
7 (N = 11)	4/7
8 (N = 14)	6/8
9 (N = 18)	6/12
10 (N = 14)	6/8
11 (N = 15)	9/6
12 (N = 13)	7/6
13 (N = 14)	8/6
14 (N = 20)	8/12
15 (N = 17)	9/8
16 (N = 18)	8/10
17 (N = 20)	9/11
18 (N = 14)	7/7
Adults (N=18)	8/10
Adult Participant Age groups*	# Males / # Females
19 (N = 0)	0/0
20 (N = 2)	1/1
21 (N = 5)	4/1
22 (N = 4)	2/2
23 (N = 3)	0/3
24 (N = 2)	1/1
25 (N = 2)	0/2

*All adult participants ages ≥ 19 were included in 1 group; the following line represent the subgroups of adults by one-year increments.

Procedure

The data for this study were previously collected in the Brainwaves Research Lab at Colorado State University. Therefore, this study represents secondary data analysis designed to answer the proposed research questions.

Stimuli Presentation

All stimuli in both paradigms were presented using Stim software (the software of the Neuroscan (Compumedics USA, 5015 West WT Harris Blvd, Suite E, Charlotte, NC 28269, USA)). Tones were presented through ER-3A inserted earphones (Etymotic Research, Inc., 61 Martin Lane, Elk Grove Village, IL 60007 USA).

Novelty Oddball (NOD) Paradigm

The novelty oddball (NOD) paradigm involved the presentation of three different tones: standard, target, novel tones. All tones were 100 ms in duration and presented at 75dB. The standard tone (600 Hz) was presented 108 times with a probability of 0.57. The target tone (1500 Hz) was presented 41 times with a probability of 0.22. Novel tones consisted of a sliding tone with either increasing or decreasing mixed frequency in the range of 600 Hz-1500 Hz, with each novel stimulus being unique from all other novel stimuli and were presented 40 times with a probability of 0.21. Tones were presented to participants, and they were instructed to press a button with their right index finger in response to the target tone (1500 Hz). Participants were instructed to ignore and not respond to any other tones (e.g., standard and novel).

Novelty Dual Task (NDT) Paradigm

In the novelty dual task (NDT) paradigm, participants were given the same instructions and tones as in the NOD paradigm. However, at the same time, participants viewed numbers displayed on a computer monitor one at a time, and when there were three sequentially-presented odd numbers (e.g. 1, 5, 7), participants were instructed to press another button with their left index finger. Numbers were presented for a duration of 400 ms with an inter-stimulus interval of 800ms.

Electrophysiological Recording

All data collected from the proposed study are EEG's recorded using a portable QucikTrace system (Neuroscan (Compumedics USA, 5015 West WT Harris Blvd, Suite E, Charlotte, NC 28269, USA)) from 29 scalp sites according to a modified 10-20 system: Fz, FCz, Cz, Pz, Oz, Fp1, Fp2, AF3, AF4, F3, F4, F7, F8, FC1, FC2, FC5, FC6, C3, C4, T7, T8, CP1, CP2, P3, P4, P7, P8, PO3, PO4, with AFz as ground (American Electroencephalographic Society, 1994).

Data Reduction Procedures

All raw EEG data obtained from the NOD and NDT paradigms were preprocessed using Analyzer 2.0 software (www.brainproducts.com). Data from continuous EEG were first referenced to the average voltage of the 2 earlobe electrodes filtered with a 0.23-30 Hz. (24 dB/octave). All tones (i.e. frequent, target, novel) were segmented from 200 ms prior to stimulus onset to 1000 ms post stimulus onset. Baseline correction was then performed on each segment from -200 ms to 0 ms relative to stimulus onset. A regression procedure was used to remove eye blinks for all segments (Segalowitz, 1996). Following this regression procedure, baseline correction was performed again with the -200 to 0 ms window. Finally, an artifact rejection procedure was used to remove segments with voltages exceeding ±150 μV. Averaged ERPs for frequent, target, and novel tone segments were calculated and retained after data collection for each participant. The data were then processed using a MATLAB routine which allows the ERP components to be automatically scored and visually inspected, and, when necessary, to be manually marked. Manual marking becomes necessary when the program does not correctly identify the peak. All ERP component measurements were carried out by 3 trained research assistants. Latency and averaged peak-to-peak amplitude were calculated for P1, N1, P2, N2, P3, N3, and P4 at Fz and Pz using a MATLAB routine. Each component was defined using a specific time window. For all age groups, the P1 was defined as the most positive amplitude in the 15-80 ms time window, N1 as the most negative amplitude in the 80- 140 ms time window, P2 as the most positive amplitude in the 120-230 ms time window, N2 as the most negative amplitude in the 150-310 ms time window, P3 as the most positive amplitude in the 220-500 ms time window, N3 as the most negative amplitude in the 300-540 ms time window, and P4 as the most positive amplitude in the 420-660 ms time window. Amplitude was measured peak-to peak. Peak-to-peak measurements were determined by subtracting the P2 amplitude from the P3 amplitude. The data were inspected to find data points with latencies outside of the set windows. For the P3 window (220ms-500ms), 5 data points were found to be early from 198ms-219 ms and 6 data points were found to be late from 504 ms to 546 ms. Outliers were visually inspected to confirm that the peak chosen outside the window was the best peak.

Statistical Analysis

To test Hypothesis 1a, Pearson correlations were performed using age and P3 amplitude at Fz and Pz as continuous variables to evaluate a potential relationship between age and P3 amplitude. These analyses were completed using the target tone, as previous work has demonstrated target tones elicit voluntary attention allocation. Similarly, Hypothesis 1b was tested using Pearson correlations using age and P3 latency at Fz and Pz as continuous variables to evaluate a potential relationship between age and P3 latency. It was found that age significantly influenced P3 amplitude and latency; therefore, age was used as a covariate for all further analyses. Therefore, Hypotheses 2a, 2b, 3a and 3b were tested using an ANCOVA. We evaluated the effect of task demand (i.e. single versus dual) on P3 amplitude and latency at Fz and Pz using age as a covariate. All these analyses used data from target tones; however, we also conducted exploratory analysis of all Hypotheses using data from novel tones.

Results

Only correct trials were included in averaging and analysis. Correct trials include correct button press responses to target tone stimuli and no responses to novel and standard tone stimuli.

Relationship between Age and P3

The first research question examined if the amplitude and latency of the P3 at Pz and Fz changes across age in response to the target tone.

Amplitude at Pz

Pearson correlations were computed to assess the relationship between age and the amplitude of the P3 at Pz using data from target tones. There was a significant negative relationship between age and amplitude in the single task paradigm, $r(209) = -0.181$, $p=0.008$. There was also a significant negative relationship between age and amplitude in the dual task paradigm, $r(204) = -0.382$, $p<0.0005$. Overall, there was a significant negative relationship between P3 amplitude and age; as the age increased, the amplitude of the P3 at Pz decreased in both paradigms. Single and dual task Pz amplitude mean and standard deviation by age group can be found in Table 2.

Amplitude at Fz

Pearson correlations were computed to assess the relationship between age and the amplitude of the P3 at Fz using data from target tones. There was a significant negative relationship between age and amplitude in the single task paradigm, $r(209) = -0.190$, $p=0.006$. There was also a significant negative relationship between age and amplitude in the dual task paradigm, $r(204) = -0.391$, $p<0.0005$. Overall, there was a significant negative relationship between P3 amplitude and age; as age increased, the amplitude of the P3 at Fz decreased in both paradigms. Single and dual task Fz amplitude mean and standard deviation by age group can be found in Table 2.

Table 2: Single and Dual Task Target Tone Amplitude Means and Standard Deviations at Fz and Pz by Age category.

Participant Age Group	Single Task Amplitude (µV) at Fz (M/SD)	Dual Task Amplitude (µV) at Fz (M/SD)	Single Task Amplitude (µV) at Pz (M/SD)	Dual Task Amplitude(µV) at Pz (M/SD)
7	15.74 /16.78	12.95/3.91	17.13/9.69	12.96/4.87
8	8.70/4.34	12.46/3.33	14.14/4.58	12.84/4.24
9	10.30/4.62	12.68/5.30	11.34/5.43	11.73/4.66
10	10.10/5.08	10.97/4.88	12.22/4.14	10.55/4.17
11	10.47/6.65	9.97/3.67	12.20/5.40	10.50/3.55
12	8.12/4.47	8.46/4.15	12.37/7.23	9.56/4.38
13	10.51/4.21	10.15/5.29	12.31/7.68	8.78/4.64
14	7.82/4.34	8.24/3.47	11.61/6.12	8.29/3.30
15	9.62/5.43	7.70/3.57	9.93/5.89	7.26/4.06
16	6.60/2.33	6.23/2.98	9.33/3.94	7.79/3.05
17	5.87/2.35	5.92/3.77	8.01/4.68	6.74/3.66
18	9.11/3.94	7.62/3.52	13.02/8.12	7.66/5.54
Adults (19-25)	9.37/5.19	8.87/2.72	11.53/6.25	7.75/3/11

Latency at Pz

Pearson correlations were computed to assess the relationship between age and the latency of the P3 at Pz using data from target tones. There was a significant negative relationship between age and latency in the single task paradigm, $r(209) = -0.144$, $p=0.037$. There was no significant relationship between age and latency in the dual task. Overall, as age increased, the latency of the P3 at Pz decreased, but only in the single task paradigm. Single and dual task Pz latency mean and standard deviation by age group can be found in Table 3.

Latency at Fz

Pearson correlations were computed to assess the relationship between age and the latency of the P3 at Fz using data from target tones. There was a significant negative correlation between age and latency in the single task paradigm, $r(209) = -0.299$, $p<0.0005$. There was no significant relationship between age and latency in the dual task. Overall, as the participant’s age increased, the latency of the P3 at Fz decreased in both paradigms. Single and dual task Fz latency mean and standard deviation by age group can be found in Table 3.

Table 3: Single and Dual Task Target Tone Latency Means and Standard Deviations at Fz and Pz by Age categories.

Participant Age Group	Single Task Latency (ms) at Fz *(M/SD)*	Dual Task Latency (ms) at Fz *(M/SD)*	Single Task Latency (ms) at Pz *(M/SD)*	Dual Task Latency (ms) at Pz *(M/SD)*
7	343.86/50.21	321.27/67.54	335.43/68.08	344.55/79.95
8	345.86/36.56	354.00/60.62	334.57/57.06	349.29/71.78
9	330.32/30.23	351.11/52.84	326.42/44.91	360.67/62.93
10	352.67/42.91	353.71/58.73	362.00/46.78	347.57/66.47
11	328.67/32.27	363.47/63.42	332.67/49.21	365.60/49.36
12	316.92/43.92	337.69/50.66	324.77/50.30	329.54/54.44
13	320.71/33.09	340.14/51.64	336.14/59.45	338.57/43.62
14	305.10/41.97	347.30/44.91	322.80/44.07	324.30/51.50
15	314.12/37.49	333.76/49.48	323.63/42.42	323.53/62.64
16	331.00/29.98	330.56/37.78	330.44/45.07	339.22/53.38
17	322.94/45.66	343.50/60.14	333.30/50.95	345.40/53.27
18	305.60/42.37	368.86/52.83	311.87/42.95	365.43/65.95
Adults (19-25)	298.78/39.95	330.22/60.25	312.44/31.75	347.67/61.90

Main Effects and Interaction Effects of Task and Age

The second research question asked if the amplitude and latency of the P3 component at Pz and Fz is affected by changing task demands (i.e. single versus dual task), and the third research question explored the interaction between age and task demands on the P3 at Fz and Pz. Given the significant relationship between age and P3 amplitude and latency, age was included as a covariate.

Amplitude at Pz

A one-way repeated measures ANCOVA was conducted to evaluate how task demands (single versus dual task) and age influenced amplitude of the P3 component at Pz during target tones. The ANCOVA revealed no main effect of task on P3. Additionally, there was no significant interaction of task demands and age on the amplitude of the P3 at Pz.

Amplitude at Fz

A one-way repeated measures ANCOVA was conducted to evaluate how task demands (single versus dual task) and age influenced amplitude of the P3 component at Fz during target tone presentation. The ANCOVA revealed a main effect of task on amplitude, as single task amplitude (*M=8.99*µV*,* *SD*=4.89µV) was smaller than dual task amplitude (*M=9.22*µV*,* *SD*=4.43µV) at Fz, $F_{(1, 203)}$ = 8.11, p= 0.005, η^2_p= 0.038. Additionally, there was a significant interaction between task demands and age on the amplitude of the P3 at Fz, $F_{(1, 203)}$ = 7.629, p= 0.006, η^2_p= 0.036. This interaction demonstrates that the P3 amplitude in response to dual tasks decreased more with increasing participant age than P3 amplitude in response to single tasks. These results are depicted in Figures 2 and 3.

Latency at Pz

A one-way repeated measures ANCOVA was conducted to evaluate how task demands (single versus dual task) and age influenced latency of the P3 component at Pz during target tone presentation. The ANCOVA revealed no main effect of task on P3 latency. Additionally, there was no significant interaction of task demands and age on the latency of the P3.

Latency at Fz

A one-way repeated measures ANCOVA was conducted to evaluate how task demands (single versus dual task) and age influenced the latency of the P3 component at Fz during target tone presentation. The ANCOVA revealed no main effect of task on P3 latency. However, the ANCOVA revealed a significant interaction of task demands and age on the latency of the P3 at Fz, $F_{(1, 203)}$ = 7.935, p= 0.005, η^2_p= 0.038. This interaction shows that the latency of the P3 in response to single tasks decreases more with increasing participant age than the latency in response to dual tasks. These results are depicted in Figure 4.

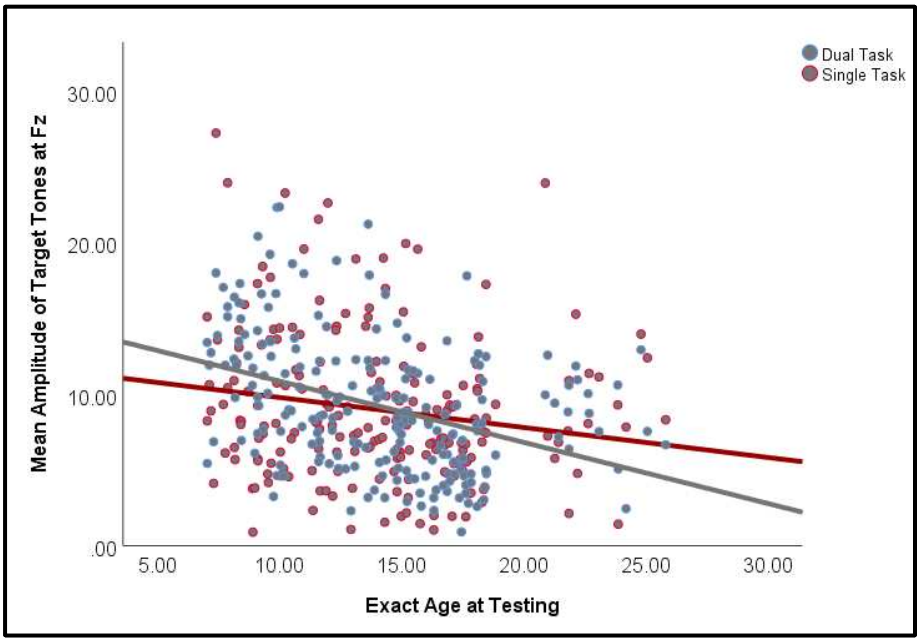

Figure 2: Interaction between age and task demands on the mean amplitude of the P3 in response to target tones at Fz. There is a significant main effect of task and main effect of age on amplitude as single task amplitude is smaller than dual task amplitude at Fz. There was also a significant interaction between age and task demonstrating that the P3 amplitude in response to dual tasks decreased more with increasing participant age than P3 amplitude in response to single tasks

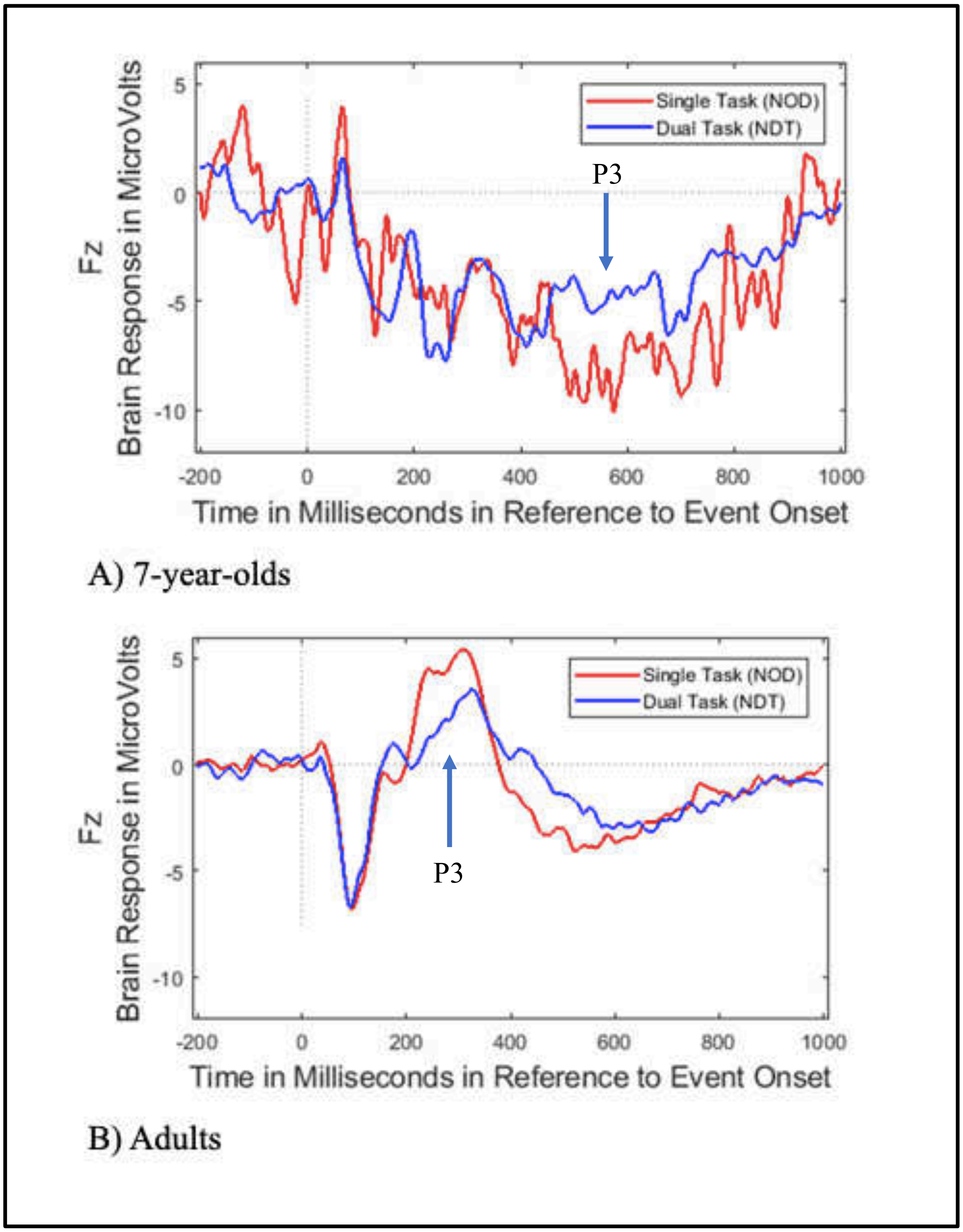

Figure 3: ERP figures displaying A) Grand average of 7-year-old participants and B) Grand average of adult participants - Target Tones at Fz for NOD and NDT plotted

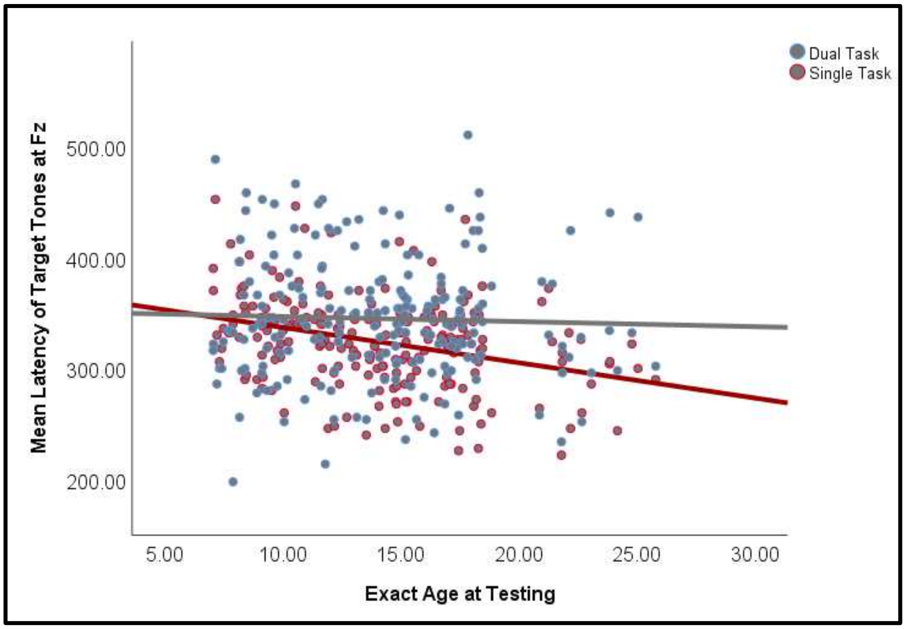

Figure 4: Interaction between age and task demands on the mean latency of the P3 in response to target tones at Fz. There is a significant interaction between age and task demonstrating that the latency of the P3 in response to single tasks decreases more with increasing participant age than the latency in response to dual tasks.

Exploratory Analyses

Exploratory analyses were conducted to answer all research questions with data in response to the novel tone at both Fz and Pz.

Relationship between Age and P3

Amplitude at Pz

Pearson correlations were computed to assess the relationship between age and the amplitude of the P3 at Fz and Pz using data from novel tones. There was a significant negative relationship between age and P3 amplitude in the single task paradigm at Pz, $r(209) = -0.183$, $p=0.008$. There was also a significant negative relationship between the variables in the dual task paradigm at Pz, $r(204) = -0.253$, $p<0.0005$. Overall, as age increased, the amplitude of the P3 at

Pz from the novel tones decreased in both paradigms. Single and dual task Pz amplitude mean and standard deviation by age group can be found in Table 4.

Table 4: Single and Dual Task Novel Tone Amplitude Means and Standard Deviations at Pz by Age category.

Participant Age Group	Single Task Amplitude (µV) at Pz *(M/SD)*	Dual Task Amplitude (µV) at Pz *(M/SD)*
7	22.07/20.59	13.64/9.26
8	14.22/4.35	12.27/3.48
9	14.39/6.56	11.27/4.39
10	15.60/6.61	10.98/4.22
11	14.48/5.06	9.99/4.50
12	15.54/6.02	9.56/4.05
13	13.19/5.98	10.97/4.97
14	13.91/6.83	10.16/4.89
15	14.23/9.01	12.25/8.22
16	13.08/5.55	8.01/4.62
17	12.87/6.43	8.36/5.13
18	16.01/7.35	11.37/5.89
Adults (19-25)	11.19/5.74	10.91/5.87

Latency at Pz

Pearson correlations were computed to assess the relationship between age and the latency of the P3 at Fz and Pz using data from novel tones. There was a significant negative relationship between age and latency in the single task paradigm at Pz, $r(210) = -0.326$, $p<0.0005$. There was a significant negative relationship between age and latency in the dual task paradigm at Pz, $r(204) = -0.230$, $p=0.001$. Overall, as age increased, the latency of the P3 at Pz decreased in both paradigms. Single and dual task Pz latency mean and standard deviation by age group can be found in Table 5.

Latency at Fz

There was a significant negative relationship between age and latency in the single task paradigm at Fz, $r(210) = -0.254$, $p<0.0005$. There was a significant negative correlation between age and latency in the dual task paradigm at Fz, $r(204) = -0.198$, $p=0.004$. Overall, as age increased, the latency of the P3 at Fz decreased in both paradigms. Single and dual task Fz latency mean and standard deviation by age group can be found in Table 5.

Table 5: Single and Dual Task Novel Tone Latency Means and Standard Deviations at Fz and Pz by Age category.

Participant Age Group	Single Task Latency (ms) at Fz *(M/SD)*	Dual Task Latency (ms) at Fz *(M/SD)*	Single Task Latency(ms) at Pz *(M/SD)*	Dual Task Latency (ms) at Pz *(M/SD)*
7	342.00/24.68	333.27/29.52	372.14/31.05	336.73/70.22
8	329.00/37.12	344.57/34.20	361.29/38.70	346.57/45.24
9	336.63/36/67	318.56/37.34	341.68/35.63	318.33/38.34
10	334.93/39.83	341.14/44.20	351.20/39.76	334.86/44.22
11	342.13/28.51	332.95/39.95	333.60/60.11	326.40/38.91
12	323.54/42.36	318.77/41.36	342.00/53.88	308.46/27.65
13	309.57/42.51	314.71/48.77	323.57/40.67	308.14/39.27
14	307.00/42.43	308.20/39.20	314.90/33.82	305.00/31.61
15	318.00/44.98	315.18/33.48	322.71/37.91	312.82/54.87
16	302.78/40.39	324.33/26.49	301.89/36.60	303.89/33.74
17	314.20/47.37	335.30/32.90	323.50/49.98	312.70/48.42
18	310.80/43.85	305.71/28.93	324.27/41.50	308.57/38.86
Adults (19-25)	308.78/43.88	304.44/32.67	319.11/35.42	303.22/36.16

Main Effects and Interaction Effects Between Task and Age

Amplitude at Pz

A one-way repeated measures ANCOVA was conducted to evaluate how task demands (single versus dual task) and age influenced amplitude of the P3 component at Pz during novel tone presentation. The ANCOVA revealed there is a main effect of task on the amplitude of the P3 as single task amplitude (M=14.08µV, SD=6.48µV) is larger than dual task amplitude (M=9.46µV, SD=4.73µV) at Pz, $F_{(1, 203)} = 5.934$, $p= 0.016$, $\eta^2_p= 0.028$. However, there was no significant interaction of task demands and age on the amplitude of the P3. These results are depicted in Figure 5.

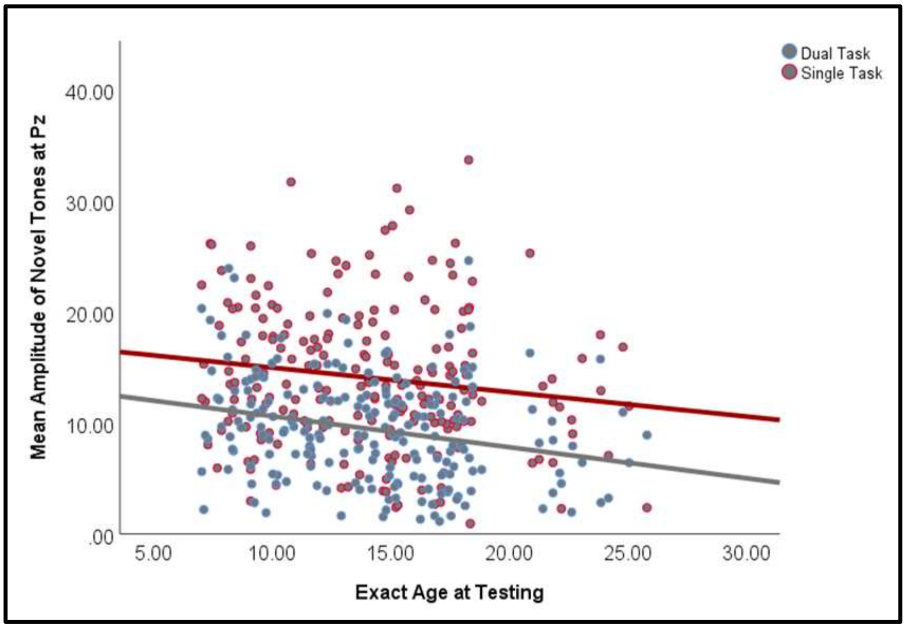

Figure 5: Relationship between age and task demands on the mean amplitude of the P3 in response to novel tones at Pz. There is a main effect of task on the amplitude of the P3 as single task amplitude is larger than dual task amplitude at Pz.

Amplitude at Fz

No significant main effect or interaction effect was found for the P3 amplitude in response to the novel tone at Fz.

Latency at Pz

A one-way repeated measures ANCOVA was conducted to evaluate how task demands (single versus dual task) and age influenced latency of the P3 component at Pz during novel tone presentation. The ANCOVA revealed there is a main effect of task on latency, single task latency (*M*=330.91ms*, SD*=44.76ms) is larger than dual task latency (*M*=316.09ms*, SD*=43.33ms) at Pz, $F_{(1, 203)} = 5.889$, $p= 0.016$, $\eta^2_p= 0.028$. However, there was no significant interaction of task demands and age on the latency of the P3. These results are depicted in Figure 6.

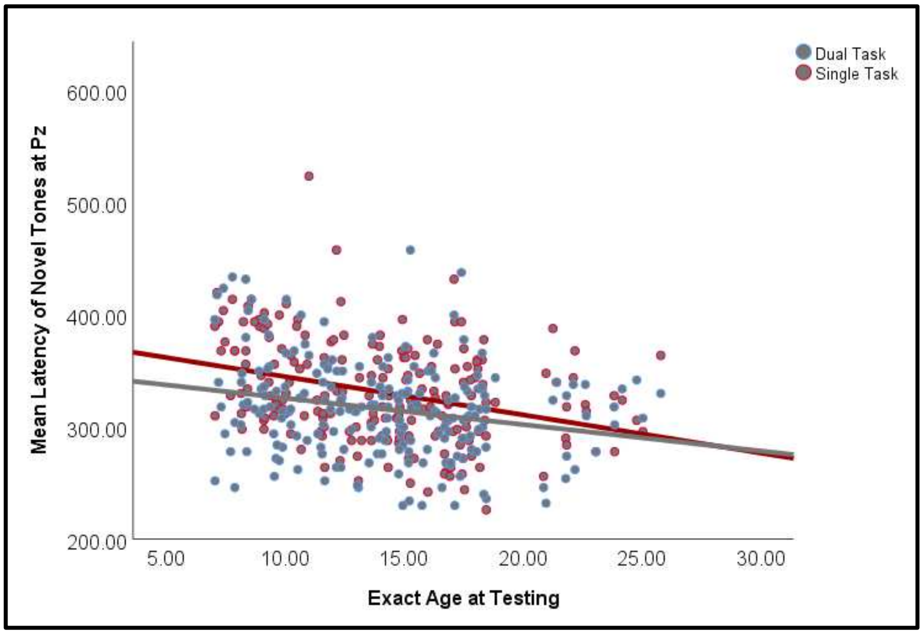

Figure 6: Relationship between age and task demands on the mean latency of the P3 in response to novel tones at Pz. There is a main effect of task on latency, single task latency is larger than dual task latency at Pz.

Latency at Fz

No significant main effect or interaction effect was found for the P3 latency in response to the novel tone at Fz.

CHAPTER 3 DISCUSSION

General Discussion

The aim of the current study was to evaluate the development of the P3 amplitude and latency in conjunction with varying task demands. We evaluated relationships between task demands and age, main effect of task demands, and interaction effects of task and age on P3 amplitude and latency at Pz and Fz.

Relationship between Age and P3

Amplitude

We found a significant, negative relationship between age and P3 amplitude for target tones at Pz and Fz for both single and dual task paradigms. This indicates that with higher ages, the amplitude of the P3 at Pz and Fz decreases. These results contradict the first hypothesis that the P3 amplitude will increase significantly with age in both single and dual task paradigms, which was based on previous findings that P3 amplitude increases with age (Kilpeläinen et al., 1999; Overbye et al., 2018; Van Dinteren et al., 2014a; Van Dinteren, Arns, Jongsma, & Kessels, 2014b). These studies suggest that P3 amplitude is an index for attention capacity and cognitive processing, and that age-related increases in amplitude represent greater attention capacity. However, it has also been theorized that age-related decreases in P3 amplitude may represent more refined or automatic attention allocation that requires less neural recruitment (Majahan & McAurthur, 2015). Previous neuroimaging studies have found that participants with TBI, compared to neurotypical controls, demonstrated more robust activation in areas of attention processing in paradigms requiring sustained attention (Smits et al., 2009; Wu et al., 2018). TBI has been shown to impact attention processes such as divided and sustained attention (Chan, 2002; Wu et al., 2018). These results support the hypothesis that a larger P3 amplitude reflects less refined or automatic attention allocation. This hypothesis may explain the results of this thesis that demonstrated that the P3 amplitude had a negative correlation with age, and that a decrease in the P3 amplitude with age represents more refined neural processing. Additionally, our study is unique in using three-tone novelty paradigm to study development. Our contradictory results may indicate that the addition of a third tone changes attention demands.

Latency

We also found a significant, negative relationship between age and P3 latency in the single task paradigm at Fz and Pz; as age increased, latency decreased. Previous research has suggested that latency reflects stimulus processing time; therefore, a shorter latency represents shorter processing time (Coles & Rugg, 1995; Kutas et al., 1977; Magliero et al.,1984). Previous auditory oddball research has demonstrated that latency decreases as the age increases, suggesting that processing time is shortening (Curry & Polich, 1992; Fuchigami et al., 1995; Fuchigami et al., 2009; Kilpeläinen et al., 1999; Mahajan & McAurthur, 2015). This shortened processing time is said to reflect cognitive maturation with age (Courchesne, 1978; Mahajan & McAurthur, 2015, Overbye et al., 2018). Our results correspond with previous work, and likely indicate that changes in P3 latency reflect cognitive maturation from childhood to adulthood. No relationship was found between age and P3 latency under dual task demands. Previous literature supports these findings as it has been demonstrated that while latency decreases with increasing age under single task demands, latency has not found to be affected under dual task demands (Jocoy et al., 1998; Wilson et al., 2012). Although we did not observe a relationship between age and P3 latency in the dual task, our study is the first to use a single and dual task paradigm across a range of ages, and we will describe those interaction effects in a later section.

Main Effects and Interaction Effects of Task and Age

Amplitude

There was no main effect of task on P3 amplitude at Pz in response to the target tone. However, there was a main effect of task on P3 amplitude at Fz in response to the target tone: single task amplitude was found to be smaller than dual task amplitude. The increase in amplitude in response to dual tasks suggests that more effortful processing results in a larger P3 amplitude, likely due to the recruitment of more frontal neural resources. While previous studies have demonstrated that the addition of a distractor task decreases P3 amplitude (Jocoy et al., 1988; Wilson et al., 2012; Wilson et al., 2014), these previous studies differ from our study in that they used two-tone paradigms.

There was no interaction of age and task demands on P3 amplitude at Pz, however, a significant interaction of age and task demand was found for P3 amplitude at Fz. This interaction demonstrated that the P3 amplitude in response to dual tasks decreased more with increasing participant age than P3 amplitude in response to single tasks. These results are supported by the previous discussion regarding smaller P3 amplitudes reflecting more refined or automatic attention allocation that requires less neural recruitment. Our results could imply that dual tasks are more effortful for younger participants, reflected in larger P3 amplitudes. A lower P3 amplitude in response to the dual tasks in older participants may be due to a practice effect as participants first engaged in the single task. Lower dual task amplitude may suggest that older participants were better able to learn how to engage in the auditory task during the single task paradigm, and therefore did not need to allocate as much attention to it in the dual task paradigm.

In a study using a three-tone novelty auditory paradigm, Katayama and Polich (1996) manipulated the probabilities of the target tone. It was found that a target tone probability of 0.10

elicited a larger P3 than a target tone probability of 0.30. Based on these findings, it could be possible that target tone probability has also had an impact the P3, given that the probability of the target tone in the current study was 0.22. Further research could be done exploring the development of the P3 through manipulation of both task demands and stimulus probability.

Latency

There was no main effect of task on latency at either Pz or Fz. Other studies exploring the effects of increasing task demands in oddball paradigms also found no effect on latency (Jocoy et al., 1998; Wilson et al., 2012). The lack of an effect of task on latency suggests that higher task demands (i.e. dual tasks) do not require the longer processing time.

No significant interaction between age and task demand was found for P3 latency at Pz; however, this interaction was found to be significant at Fz. Figure 4 demonstrates that latency of the P3 in response to single tasks decreases more with increasing participant age than the latency in response to dual tasks. Our results may suggest that the amount of time required to process in a dual task paradigm is consistent across ages. These results demonstrate that when task demands interact with age the amount of time to process stimuli is significantly affected. Our results contribute to the growing body of literature that suggests that attention changes with age; however, this is the first study to look at the interaction between age and task demands on P3 latency in a large neurotypical cohort using a three-tone novelty paradigm.

Limitations

Participants in this study were recruited using a convenience sample with all participants coming from the local community. This type of recruitment may limit the generalizability of the results to a larger population. Additionally, this was a cross-sectional rather than longitudinal study. The findings in this study indicate novel findings that suggest neural measures of attention are related to participant age, and that age interacts with task demands to impact attention in a three-tone novelty auditory oddball paradigm. Future research can strengthen these findings by exploring changes in the P3 longitudinally rather than cross-sectionally.

Exploratory Analysis and Future Directions

Exploratory analyses were used to evaluate the effects of age and task demands on P3 amplitude and latency elicited by novel tones. Previous research has demonstrated that the target tone typically elicits the P3b in response to voluntary attention allocation (Knight, 1984; Strobel et al., 2008; Volpe et al., 2007; Wronka, et al., 2008), which is why the target tone was the focus of the main analyses. However, the majority of the literature looks at two-tone paradigms. It could be possible that a three-tone novelty paradigm manipulates attention differently than a two-tone paradigm. Therefore, we chose to also look at effect of age and task on amplitude and latency at Pz and Fz in response to novel tones.

Relationship Between Age and P3

We observed a significant negative relationship between age and amplitude, as well as age and latency of the P3 in response to novel tones. A significant negative relationship was found between age and amplitude of the P3 at Pz in both single and dual task paradigms; as age increased, amplitude decreased. We also observed a significant negative relationship between age and latency of the P3 at Pz and Fz in both single and dual task paradigms. These results again suggest that attention develops throughout childhood to young adulthood.

Main Effects and Interaction Effects Between Task and Age

Interestingly, a significant main effect of task on both P3 amplitude and latency in response to the novel tone was found at Pz. Single task amplitude was found to be larger than dual task amplitude. This is the opposite of what we found in response to the target tone; where dual task amplitude was larger than single task amplitude. A larger single task amplitude in response to the novel tone may suggest that the dual task takes up so much attention capacity and involuntary attention allocation to the task-irrelevant novel tone is decreased, reflected in lower P3 amplitudes. Additionally, it was found that single task latency was larger than dual task latency. This suggests that the dual task paradigm caused attention to be allocated faster than in the single task paradigm.

Scalp Sites

Given that our paradigm was unique from previous literature in that we used three-tone paradigm while also manipulating task demands, we looked at both Fz and Pz in response to both novel and target tones to get a more complete picture of attention allocation as measured by the P3. Based on previous literature, it was expected we would find significant differences in response to the target tone at the Pz scalp site and in response to the novel tone at the Fz scalp. However, we found significant differences at Fz in response to the target tone and at Pz in response to the novel tone. While these results were slightly surprising, to our knowledge this is the first study that looked at attention allocation in a three-tone oddball paradigm under differing task demands in a large neurotypical cohort. These results provide novel findings on how voluntary and involuntary attention is allocated across a broad range of ages.

Clinical Populations

Future research could also explore the effects of divided attention in clinical populations that are more at-risk for attentional deficits. One example population that is currently receiving a lot of media and research attention is athletes with sports-related concussion (SRC). It is well-documented that concussions can have long-term effects on attention allocation (Chan, 2002; Shah-Basak et al.,2018; Smits et al., 2009; Wu et al., 2018), particularly when athletes engage in dual tasks (Howell, Osternig, & Chou, 2018; Rahman et al., 2018; Wilson et al., 2014). Our findings support that increasing task demands affects attention differently across different ages. Future research could use a similar approach to explore the impact of increasing task demands in participants of various ages with SRC. Such data could highlight potential consequences of SRC-induced attention deficits, as many everyday activities rely on divided attention or attention switching skills.

Conclusions

Our findings show that both amplitude and latency of the P3 at Pz and Fz are affected by the age of the participant, suggesting that attention allocation and recruitment changes with age. During target tone presentation, there were no significant differences in P3 amplitude and latency at the Pz between single and dual tasks. However, there was a significant effect of task on P3 amplitude at Fz in response to the target tone, as single task amplitudes were smaller than dual task amplitudes, suggesting the dual task paradigm was more effortful. As most previous work used a two-tone paradigm, it is possible that the use of a three-tone novelty paradigm manipulates attention differently than what was hypothesized based on previous literature. No main effect of task or interaction of task and age was found for either amplitude or latency of the P3 at Pz in response to the target tone, but a significant interaction of age and task demand was found on amplitude at Fz in response to the target tone, demonstrating that in the dual task, P3 amplitude is smaller in adults and children. Larger P3 amplitude in children suggests that dual tasks are more effortful in younger participants. A significant interaction of age and task demand was also found for latency at Fz in response to the target tone, demonstrating that in the dual task, latency was smaller in adults than children. This may suggest that the amount of time to process dual tasks is consistent across ages. Therefore, we observed an impact of increasing task demands on attention, and this impact varies with age. Finally, previous literature has indicated P3b amplitude can be manipulated by changing the probability of the presentation of the target tones. Future research could explore how stimuli probability impacts the P3b in a three-tone novelty paradigm and examine this effect across ages, as well as in response to different tones (i.e. novel and target). Future directions could incorporate neuroimaging to explore attention during differing task demands in populations with brain injury including SRC. This would serve to determine long-term attention deficits and potential occupational performance concerns in these populations.

Connections to Occupational Therapy

International Classification of Functioning

The World Health Organization's (WHO) (2002) International Classification of Functioning (ICF) has served as the conceptual basis for the description of health and disability in Rehabilitation Science. The ICF has been used within research and philosophy in occupational therapy (OT) to inform best practice and definitions of disability in the 21st century. The ICF's model of disability (Figure 7) acknowledges that it is not only the diagnosis or health condition that impacts disability, but factors such as body functions and structure, environment, and personal factors. The arrows depicted in the model indicate that these factors are fluid and all impact and are impacted by other factors within the model.

The research and conclusions made from the results of this thesis explored attention allocation and divided attention at the neural level. Within the ICF model, attention would fall under body functions and structures. Results demonstrated that attention is manipulated under differing task demands. Our results also demonstrated that measures of attention change with age, and that task demands significantly interact with age to impact attention.

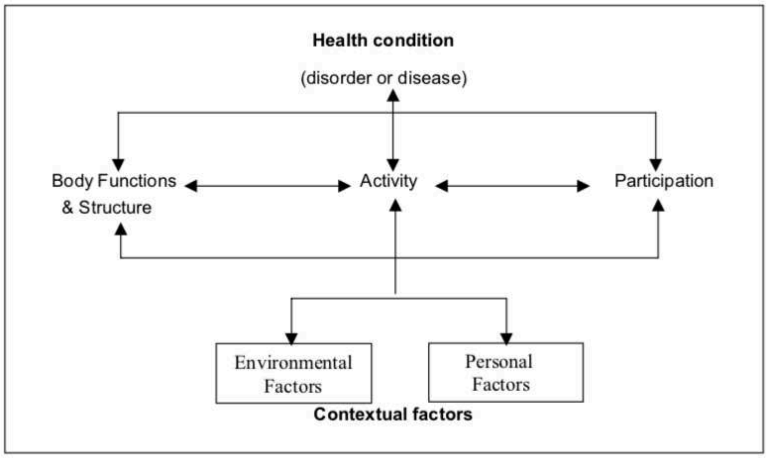

Figure 7: WHO's (2002) model for the ICF following the biopsychosocial model of disability (p. 8)

The ICF suggests that body functions and structure impact and are impacted by activities, health conditions, participation, and contextual factors. While the task in our paradigm was fairly simple, an impairment in attention allocation or divided attention can have an impact as activities become more complicated. The implications for deficits in divided attention become more significant when considering the ADLs and IADLs an individual participates in every day that require divided attention.

These implications become even more significant when health conditions, such as TBI and SRC, also impact attention. It has been found that brain injury impacts the brain's functions including deficits in divided attention (Stuss et al., 1989) and reduced ability to filter task-irrelevant stimuli (Anderson, Catroppa, Morse, Haritou, & Rosenfeld, 2005). According to the ICF's model, such an impact on the function of the brain can have implications for an individual's activities and participation.

Finally, age is considered a personal factor within the ICF that interacts with all other factors to facilitate participation in activities. The results of this thesis demonstrated that attention changes with age, and that dual tasks are more effortful in younger participants (young children) compared to older participants (young adults). These normal age-related changes in attention will impact the activities a child participates in as compared to an adult. However, deficits in brain function as the result of a health condition has the potential to impact activities across the lifespan that require divided attention.

While the scope of OT is broad, the ultimate aim of the profession is to support performance and participation in clients' valued occupations. OT is uniquely positioned to facilitate performance and participation given in-depth training on how the environment, personal factors of the individual, and the desired occupation interact to impact engagement in occupation. It is well documented that participation in occupations that are meaningful to the individual has the power to improve health outcomes and well-being across the lifespan (Law, 2002). Additionally, participation in occupations supports the acquisition of new skills across all ages (Law, 2002). The results from this thesis inform the body structures and function factor on the ICF model of disability, as well as personal factors such as age. Further research can inform how heath conditions interact with these body functions and structures, as well as age to impact an individual's activities and participation. Previous research has demonstrated that behavioral measures of gait performance disintegrate under dual task demands, especially in clinical populations of children with brain injury (Catena, Donkelaar, & Chou, 2006; Howell et al., 2018; Rahman et al., 2018). Such research along the ICF continuum could be used to inform both remedial and compensatory OT interventions that can be used to facilitate performance and participation across all ages despite deficits in attention. Additionally, the results of this thesis demonstrate neurological systems are impacted by varying attention demands and by age, which may serve as a starting point for intervention studies aimed at remediating attentional deficits.

ICF and Evidence-Based Practice

The American Occupational Therapy Association's (AOTA) Centennial Vision for the profession of occupational therapy expresses a desire for OT to become a "powerful, widely recognized, science-driven, and evidence-based profession with a globally connected and diverse workforce meeting society's occupational needs" (AOTA, 2007, p. 613). To fulfil this call to become a science-driven and evidence-based profession, research along the ICF continuum is necessary to achieve a greater understanding of the interactions between health conditions, body structures and functions, activities, personal and contextual factors that can influence performance and participation in occupation. Research from this thesis describes body functions and structures impacting activity and occupation and suggests potential impacts of health conditions and age on those body functions. This research and its future directions can serve to inform OT assessments and treatments that can mitigate the impact of divided attention tasks on task performance, specifically in clinical populations.

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