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Effects of Hypertension and TBI on Executive Functioning in Middle-to-Late Adults

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ABSTRACT

A rapid increase in age related diseases, such as Alzheimer's Disease (AD), is causing such conditions like cognitive decline to become a public health concern (Kelly & Petersen, 2007). Many studies have shown a relationship between hypertension and traumatic brain injury (TBI) with cognitive decline (such as executive functioning) respectively (Obisesan et al., 2008; Ramos-Cejudo et al., 2018). There have been few studies involving both conditions and specifically analyzing their interaction on executive functioning. Therefore, this study will investigate the effects of hypertension on executive functioning in patients with TBI compared to those without TBI. Executive function will be measured using the Trail Making Test Form B, WAIS-III Digit Span Forward & Backward, and Verbal Fluency Test FAS. Expected results included significant main effects of blood pressure and TBI individually on executive functioning. Additionally, it was predicted that there would be a significant interaction between TBI and blood pressure on executive functioning. Results indicated a significant main effect of TBI presence on working memory and verbal fluency, but not on inhibitory control. There was a significant main effect of blood pressure on inhibitory control, but not on working memory and verbal fluency. The results indicated that there was a significant interaction between TBI and blood pressure on working memory performance. Therefore, the study found that hypertension and TBI affect long-term executive functioning s depending on the form of executive functioning. Future studies may investigate the functional connectivity associated with the interaction between TBI and blood pressure on executive functioning.

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Introduction

Over the past few decades, human life expectancy has been increasing. More specifically, Christensen et al. (2009) indicate an increase in life expectancy of about 30 years in developed nations such as the United States, Western Europe, Australia, Canada, and New Zealand in the 20th century. Within the United States, this is largely due to improvements in the control of childhood infectious diseases, nutrition, housing, hygiene, and medical care. In terms of specific illnesses such as heart disease, advances in medical technology have resulted in significant improvements in patient outcomes (Fenelon, et al., 2016). This, compounded by a reduction in mortality, has increased the number of older-aged adults. However, with this increasingly aging population, high rates of diseases in elderly populations are being detected (Christensen et al., 2009). One common symptom of age-related diseases is progressive cognitive impairment. According to the Center for Disease Control, cognitive impairment occurs when an individual has difficulty remembering, learning, concentrating, or making everyday life decision (*Cognitive impairment,* 2011).

While other nations have shown trends for a decline in the risk of dementia, statistics on the United States show increasing dementia related disparities particularly among socioeconomic status and race/ethnicity. Chen & Zissimopoilus (2018) indicate that African Americans and Hispanics are 2.0 and 1.5 times, respectively, as likely to get dementia as white individuals. In addition to this education, various environmental factors such as wealth and education were seen to be related to dementia as well. These were seen as likely interacting with geographical factors

that interact with qualities of schools, employment choices, financial resources, and access to quality healthcare.

Diseases causing cognitive decline can also largely affect individual families and public policies. Caring for those affected by rapid cognitive decline can cause a large burden on families. Those who choose to use long term institutional care may suffer from high financial costs. This can influence not only family dynamics but also large public programs such as Social Security, Medicare, and Medicaid (Langa, 2018). Between 2010 and 2050, the cost of care for affected persons is likely to increase from $181 billion to $1.1 trillion dollars (Chen & Zissimopoilus, 2018). These disparities and effects cause cognitive decline to be a pressing issue within the United States at an individual and national level.

Because of this pressing issue, an increasing number of studies are focusing on the causes of rapid cognitive decline. These studies provide insight into potential future studies which focus on preventative measures for cognitive decline and age-related diseases affecting the ever-increasing aging population. Two commonly cited factors in cognitive decline are traumatic brain injuries (TBI) and high blood pressure (hypertension) (Obisesan et al., 2008; Ramos-Cejudo et al., 2018).

Traumatic Brain Injuries

According to the CDC, in 2014, 56,800 U.S. citizens died from TBI related deaths and many more were injured (TBI-related Deaths). Today, studies increasingly describe a link between TBI and dementia related diseases (Ramos-Cejudo et al., 2018). These studies have shown pathological links between TBI and neurodegeneration and dementia. Specifically, they

indicate similar neuropathic changes in patients with head injuries and those with neurological disease. Symptoms of dementia related diseases can include executive functioning deficits. Executive functioning is a neurocognitive process which controls thoughts and behaviors toward achieving an objective. As a result, these functions regulate behavior, cognitive, and emotional activity. These functions also help to regulate adaptive capabilities (Pascual et al., 2019). A study conducted by Krasney-Pacini et al., (2017) investigated the effects of severe childhood traumatic brain injury on executive function. This prospective longitudinal study involved children, ages 0-15, with Glasgow Coma Scale (GCS) scores less than 8 or an Injury Severity Score greater than 16 - representing significant TBI. Children were selected from the University Necker Enfants Malades Hospital. To test for executive functioning, they used the Behavior Rating Inventory of Executive Functions (BRIEF) questionnaire measuring inhibition, working memory, metacognition index, and behavioral regulation index. They also used the attention sub score of Child Behavior Checklist (CBCL). They found that the children with TBI had significant impairment to working memory, inhibition, attention, and global executive function with little to no recovery at 24 months. Children had impairments in flexibility and performance based executive functioning for up to 3 months (Krasney-Pacini et al., 2017). These results provide evidence for a potential relationship between TBI and executive functioning deficits. Therefore, by increasing research on cognitive decline post-TBI, researchers can potentially delay the onset of dementia related symptoms.

Tsai et al. (2021) found similar results in their metanalysis. They assessed prospective, retrospective, and cross-sectional designs showing the prevalence of cognitive deficits after TBI in three phases – acute, subacute, and chronic phases. In the chronic phase, they found that 21% of participants had memory deficits, 50% had attention deficits, 47% had information processing

speed deficits, and 38% had executive dysfunction (Tsai et al., 2021). These results show that the literature overarchingly shows a potential relationship between cognitive decline and TBI. This study was largely supported by a metanalysis by Ruttan et al. (2008), examining long-term outcomes of individuals with moderate to severe TBI. The study assessed individuals both 6-18 months post injury and 4.5-11 years post injury. They used 1380 subjects over 16 studies that met their inclusion criteria. Overarchingly, they found residual cognitive deficits in both time periods. This was seen even when researchers parceled out processing speeds (often associated with aging) from neuropsychologic tests of verbal learning/recall, visuospatial learning/recall, prospective memory, executive functioning, mental efficiency, and visuospatial skills (Ruttan et al., 2008). This finding was particularly important because it shows that cognitive deficits exist beyond those caused by old age. More specifically, TBI was found to be related to an increase in cognitive decline and dementia related symptoms. This shows that TBI is a pressing factor for cognitive decline that must be analyzed further.

Hypertension

Similarly, many studies are showing a link between hypertension and cognitive decline. One study investigated the impact of hypertension, high blood pressure (BP), and high pulse pressure (PP) on cognitive function (Obisesan et. al., 2008). The researchers hypothesized that hypertension, high BP, and high PP would be independently associated with lower cognitive functioning. The authors found that higher BP, PP, and hypertension was associated with poorer cognitive functioning than normal blood pressure. They also found that control of blood pressure was associated with increased resiliency to hypertension-related cognitive decline. These results

were independent of age, sex, ethnicity, education, income, and history of stroke (Obisesan et. al., 2008).

This was then substantiated by a second study with the objective to determine if hypertension is associated with mild cognitive impairment (MCI) (Reitz et. al., 2007). They found that hypertension was associated with increased risk of all-cause MCI. Additionally, hypertension was even strongly correlated with increased risk of nonamnestic MCI ($p=0.009$). There was no association between hypertension and amnestic MCI ($p=0.49$) indicating that hypertension may more so affect nonamnestic cognition (such as executive functioning) rather than amnestic (Reitz et. al., 2007). While Obisesan et. al., (2008) supports the presence of cognitive deficits, it did not specify the condition of mild cognitive impairment as seen in Reitz et. al. (2017). By doing so Reitz et. al. (2017) potentially associates hypertension with Alzheimer's - which has the intermediate stage of mild cognitive impairment symptoms. By looking at two different studies focusing on the cognitive effects of hypertension this provides substantial evidence for the relationship between hypertension and a form of cognitive decline: nonamnestic.

While these studies were substantial in associating hypertension and TBI to cognitive decline, there were multiple limitations to their practice. For example, Obisesan et. al. (2008) did not control for some confounding factors such as TBI. Given the results of previous studies, TBI has been seen to affect cognitive functioning (Xiao et. al., 2015). Therefore, the relationship between hypertension and cognitive decline may be affected by TBI. Given this and lack of control for TBI, increased research in different populations would be beneficial to understanding dementia and cognitive decline.

Current Study

While research has been conducted on executive functioning deficits in people with hypertension, little research has been done on comorbid effects of hypertension and TBI two or more years post injury. Current studies indicate a potential pathological link between TBI and early vascular dysfunction. Specifically, they have found that Tau pathology, diseases arising from the Tau's role in neurofibrillary tangle formation, in chronic traumatic encephalopathy (CTE) has been linked to cardiovascular diseases (CVD). Specifically, they found the presence of hyperphosphorylated tau proteins and accumulations of pre-tangles in small blood vessels of cortexes of the brain (Ramos-Cejudo et al., 2018). In a review conducted by Krishnamoorthy et al. (2018), they indicated that in non-injured brains, cerebrovascular autoregulatory mechanisms maintain constant cerebral blood flow and intercranial pressure (ICP). However, in injured brains, an increase in systemic blood pressure caused an increase of pressure in cerebral capillaries due to the disruption in autoregulatory mechanisms. This caused a breakdown of blood-brain barrier, cerebral edema, and increased ICP. While these results show a relationship between trauma related brain injuries and blood pressure, blood pressure was largely assessed in the brain. Therefore, systemic blood pressure as an indicator of cardiovascular fitness was not indicated. Krishnamoorthy et al. (2018) also found that early hypertension was associated with worsening outcomes in TBI participants such that patients with both hypotensive and hypertensive admission had a higher risk for mortality while in the hospital. However, these studies lacked data on the blood pressure and cognitive performance of participants long-term post-injury.

Given the complex nature of human beings, it is important to also assess how these factors impact cognitive functioning long-term. Hypertension and TBI, respectively, have often been indicated as such risk factors for cognitive decline, as evidenced previously. However, few studies have assessed the effects of both these risk factors on executive functioning performance long-term. This research is important because it helps to assess how the presence or absence of multiple risk factors at one time can influence long-term executive functioning performance. This is particularly important for physicians when assessing the behavior and functioning of older-age populations as a result previous injury. This will provide insight on why potential differences in executive functioning in individuals arise.

Given this lack of research, this study investigated nonamnestic cognitive decline in terms of executive functioning. More specifically, this study investigated the effects of hypertension on executive functioning in patients with TBI compared to those without TBI two or more years post-injury. This study varies from previous studies by assessing hypertension and executive functioning two or more years post injury. The first conceptual independent variable was cardiovascular health. The second conceptual independent variable was TBI. The dependent variable for this study was executive functioning. The following hypothesis were assessed:

Hypothesis 1:

There will be a significant main effect of BP. Those with high BP will have lower executive functioning than those with not high BP when TBI is controlled.

Hypothesis 2:

There will be a significant main effect of TBI on executive functioning. Those with TBI will have lower executive functioning than those with no TBI when BP is controlled.

Hypothesis 3:

There will also be an interaction. High blood pressure will affect executive functioning differently at levels of TBI such that those with TBI and high blood pressure will perform the worst on executive functioning tasks.

Method

The independent variable of cardiovascular health was operationalized using blood pressure measurements. The second independent variable of TBI was operationalized using GCS scores at the time of impact and Injury Severity Scores (ISS). The dependent variable of executive functioning was operationalized using The Trail making Tests Form B (TMT)/ Trail Making Tests Form A, Verbal Fluency Test FAS, WAIS-III Digit Span Forward & Backward. This material is based upon the work supported by The Pennsylvania Department of Health. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author and do not necessarily reflect the views of The Pennsylvania Department of Health.

Design

This study was a 2 (BP: high, not high) X 2 (TBI: those affected, those not affected) between subject's factorial design with executive functioning scores as the dependent variable. Executive functioning was measured using three domains – attention/mental flexibility, verbal fluency, and working memory. Each domain was measured by a test - TMT Form B/TMT Form A measured attention/mental flexibility or inhibitory control, Verbal Fluency Test FAS measured verbal fluency, and WAIS-III Digit Span measured working memory.

Participants

Participants and data were provided as part of a larger protocol funded by The Pennsylvania Department of Health (PA-DOH) which includes data from Hershey Medical Center in Hershey, PA, Moss Rehabilitation Institute in Philadelphia, PA, and Penn State University Park, University Park, PA. The PA-DOH is supported by state funds. This material is based upon the work supported by The Pennsylvania Department of Health. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author and do not necessarily reflect the views of The Pennsylvania Department of Health. Participants included individuals from middle to late adult hood (ages 51-92). Participants were excluded if they had a history of neurodevelopmental and psychiatric disorders such as schizophrenia, bipolar disorder, and autism. Participants who inaccurately reported injury history and/or had prior head injury were also excluded. ADHD and substance use were not excluded because these populations are not significantly represented in TBI. Excluding these participants would make the sample nonrepresentative of typical patients observed at clinics. Participants only involved those who were able to come to Penn State Hershey Campus, Penn State University Park Campus, and Moss Rehabilitation Campus for analysis. Only participants with a history of TBI one year or more prior to the study will be included. Participants were be excluded if they are receiving treatment for associated injuries such as orthopedic injuries or spinal cord injuries. Based on the exclusion criteria 126 participants were included. 99 participants were affected by TBI and 26 participants were Healthy Controls (Table 1). Table 1 presents the demographical breakdown of the participants included in this study.

Materials

For this study, a blood pressure cuff was used to measure the BP of participants using systolic and diastolic measures. Additionally, TBI history was assessed by self-report, interview, and medical records when provided. Participants in TBI affected groups needed to have a GCS scale score between 3-12. The Glasgow Coma Scale assesses the extent of cognitive impairment. This scale specifically assesses participants based on three behaviors of responsiveness – eye verbal and motor responses, and eye-opening. The aggregate of the different statistics provides a summary statistic between 1(no response) to 15 (normal response) (Jain, 2020). This has been previously used to assess TBI in Krasney-Pacini et. al. (2017) described in the introduction. Additionally, the Injury Severity Score (ISS) was used to assess the severity of injury. The purpose of the ISS was to predict mortality because of trauma and the quality of care needed to be provided (Geiger et al., 2011). This scale was used to determine whether affected individual had severe (scores of 16 and above), moderate (9-15), or mild injuries (less than 9) (Geiger et al., 2011).

To measure executive functioning the study used three tests - the Trail Making Tests Form B, Verbal Fluency Test FAS, and WAIS-III Digit Span. A review conducted by Faria, et al. (2015), analyzed the most frequently used tools to assess executive functioning in older adults in clinical and experimental research. In this review they found that out of 25 articles TMT Form B, Verbal Fluency Test FAS, and WAIS-III digit span were one of the seven most frequently used tools to study executive functioning. In TMT Form B test participants draw lines to connect a series of circles of letters and numbers that alternate in sequential order (ex. 1-A-2-B). Numbers go up to 13 and letters go up to M. This test specifically assessed cognitive processes

such as attention, visual search and scanning, sequencing, and shifting, psychomotor speed, abstraction, flexibility, and the ability to execute and modify a plan of action. These are all components of executive functioning (Salthouse, 2011). The present study calculated a ratio of TMT form B/ form A t-scores. By calculating a ratio of TMT B over TMT A, this alleviated a potential confound of motor function deficits.

For the Verbal Fluency Test FAS, participants were asked to name different words in each category for 60 seconds. Participants orally stated words beginning with the letters F then A then S. This test assessed deficits in attention, long-term memory, mental flexibility, ability to inhibit responses, and processing speed (Opasso et. Al., 2016).

WAIS-III Digit Span subjects were read a series of numbers and then asked to repeat the sequence back in forward or reverse order. The purpose of the forward span was to assess attention efficiency and capacity while the backward span assesses executive tasks such as working memory. This study used the Digit Span Backward and Forward (Fink et. Al., 2014).

As stated before, executive functioning is a neurocognitive process which controls thoughts and behaviors toward achieving an objective (Pascual et. al., 2019).

Procedure and Participant Grouping

For the purposes of this study, it was a goal to differentiate participants based on their blood pressure. In Obisesan et. al. (2008), cardiovascular health, the independent variable, was operationalized by blood pressure measurements. They did so by treating individuals with systolic above 140 and diastolic above 90 as high blood pressure groups and those with systolic below 140 and diastolic below 90 as a low blood pressure group. Participant blood pressures

were measured using a blood pressure cuffs. Participants in the present study were differentiated based on their high blood pressure (systolic above 140 or diastolic above 90) and low blood pressure (systolic below 140 and diastolic below 90). These participants were further divided based on control participants (those who have not been affected with TBI) and TBI participants (those who have been affected with moderate to severe TBI (GCS of 3-12)). GCS/TBI was based on self-report/patient history of TBI provided by participants. Participant medical history was also be checked to ensure TBI self-report. These characteristics provided four distinct experimental groups – TBI affected High BP (N= 39), TBI affected Not High BP (N=60), Control High BP (N=12), Control Not High BP (N=14).

To analyze executive functioning capabilities, Bangen et. al. (2010), used TMT Form B. They studied the variations in functional abilities due to mild cognitive impairment subtypes. For this they administered a comprehensive neuropsychological assessment that involved this test to all participants. Similarly, to study executive functioning, this study will also use TMT form B, along with Verbal Fluency Test FAS, and WAIS-III Digit Span. Mimicking this, following the selection of participants and blood pressure check, the dependent variable of executive functioning in the present study was analyzed using the TMT Form B/Form A to measure attention/mental flexibility, Verbal Fluency Test FAS to measure verbal fluency, and WAIS-III Digit Span Forward & Backward to measure working memory as part of executive functioning. All scores were based on raw scores, not scaled scores. Participants took this within a larger Neurocognitive Battery Test administered by the Penn State Clinical Neuropsychology Lab led by Dr. Frank Hillary and at the Moss Institute Rehabilitation Institute. Scores in TMT were based on a ratio of TMT Form B/Form A T-scores. Verbal Fluency Test FAS was scored by the number of responses minus any errors including repeats, proper nouns, or words that are out of

category. WAIS-III Digit Span were be scored by the maximum number of digits correctly stated (Fink etl. Al.). All scores and analysis were based on raw scores, not scaled scores. Following this an ANOVA analysis was conducted by calculating the average results and significance of each group using both R-Studio and Microsoft Excel (through the Microsoft office platform). Data was compiled into a document using Microsoft Word.

Results

Overview

An ANOVA analysis was used to examine the interaction of TBI and hypertension on executive functioning in middle to late adults. This study included three 2 (blood pressure: High, Not High) X 2 (TBI: those affected, those not affected) between subject's factorial design. The dependent variable were executive functioning metrics of TMT form B/A, Verbal Fluency Scores FAS, Digit Span Forward, and Digit Span Backward.

Hypothesis 1: Main Effects of Blood Pressure on Executive Functioning

Results showed that blood pressure had a significant main effect on TMT B/A T-score, $F(1,123)=5.3551$; $p=.022$ (Table 2) such that participants with high blood pressure ($M=1.07$) had lower scores than healthy controls ($M=0.97$) (Figure 1) Therefore, the null hypothesis that blood

pressure does not affect measured attention/mental flexibility or inhibitory control (measured by TMT B/A T-score) was rejected.

Results showed that blood pressure did not have a significant main effect on Digit Span Forward Raw ($F(1,125)=0.0253$; $p=0.87$) such that participants with high blood pressure ($M=9.23$) did not have significantly different scores than those without high blood pressure ($M=9.05$) (Figure 1). Results showed that blood pressure did not have a significant main effect on Digit Span Backward Raw, $F(1,125)=0.4566$; $p=0.50$, such that participants with high blood pressure ($M=7.77$) did not have significantly different scores than those without high blood pressure ($M=7.41$) (Figure 1). Therefore, the null hypothesis that TBI does not have a significant main effect on working memory was not rejected.

Finally, results showed that blood pressure had a significant main effect on Letter Fluency FAS, $F(1,125)=10.2524$; $p = 0.0017$, such that individuals with high blood pressure ($M=34.42$) had lower scores than those without high blood pressure ($M=35.04$) (Figure 1). Therefore, the null hypothesis that TBI does not affect verbal fluency was be rejected (Table 2).

Hypothesis 2: Main Effects of TBI on Executive Functioning

Results showed that TBI had a significant main effect on Digit Span Forward, $F(1,125)=11.5186$; $p<0.001$, such that individuals with TBI ($M=8.75$) had lower scores than healthy controls ($M=10.52$) (Figure 1). Additionally, results showed that TBI had a significant main effect on Digit Span Backward $F(1,125)=7.4827$; $p= .0072$, such that individuals with TBI ($M=7.26$) had lower scores than healthy controls (8.63) (Figure 1). Therefore, the null hypothesis that TBI does not affect working memory was rejected (Table 2).

Results indicated that TBI presence had a significant main effect on Letter Fluency Raw Scores, F(1,125)=10.2524; 0. 0017, such that individuals with TBI (*M*=32.66) had lower scores than healthy controls (*M*=42.59). Therefore, the null hypothesis that TBI does not affect verbal fluency was rejected (Table 2).

Results indicated that TBI presence did not have a significant main effect on Trails B/A T-Score, F(1,123)=0.0289; p=0.87, such that individuals with TBI (*M*=1.01) did not have significantly different scores (more errors) than healthy control participants (*M*=1.01). Therefore, the null hypothesis that TBI does not affect verbal fluency was not rejected (Table 2).

Hypothesis 3: Interactional Effects between TBI and Blood Pressure on Executive Functioning

To analyze the presence/absence of an interaction, this study analyzed each condition as seen in (Table 2). Results did not indicate a significant interaction between blood pressure and TBI on TMT Form B/A, F(1,123)=0.26; p=0.61. When participants were affected by high blood pressure and TBI (*M*=0.93), these participants did not have a significantly different T-scores in TMT Form B/A than those with high blood pressure who were not affected by TBI (*M*=0.97). When participants were affected by not high blood pressure and TBI participants (*M*=1.03), participants did not have significantly different T-scores in TMT Form B/A than those who are not affected by TBI (*M*=1.02) (Figure 1).

Results did not indicate a significant interaction between blood pressure and TBI on FAS Raw Score, F(1,125)=0.82; p=0.37. Participants affected by high blood pressure and TBI (*M*=31.15) did not have significantly higher scores in FAS than those who were not affected by

TBI (*M*=33.63). Participants not affected by not high blood pressure and TBI (*M*=41.07) did not have significantly different scores in FAS than those who were not affected by TBI (*M*=44.23) (Table 2).

Results did indicate a significant interaction between High Blood Pressure and TBI with Digit Span Forwards Raw, F(1,125)=4.59; p=.034 (Table 2). More specifically, there was a significant difference in scores between individuals affected with TBI and high blood pressure compared to participants with high blood pressure but not TBI (Table 2). Post hoc analysis of Digit Span Forward data indicated a significant performance deficit in TBI participants (*M*=8.711) compared to healthy control participants (*M*=11.18) with high blood pressure ($p<0.05$). There was no significant difference in performance deficits in TBI participants (*M*=8.97) compared to healthy control groups (*M*=8.75) with Not High blood pressure.

Results did not indicate a significant interaction between blood pressure and TBI on Digit Span Backwards Raw, F(1,125)=0.1316; p=0.72 (Table 2). When participants were affected by high blood pressure and TBI (*M*=7.39), these participants did not have a significantly different T-scores in TMT Form B/A than those with high blood pressure who were not affected by TBI (*M*=8.92). When participants were affected by not high blood pressure and TBI participants (*M*=7.18), participants did not have significantly different T-scores in TMT Form B/A than those who are not affected by TBI (*M*=8.36) (Figure 1).

Exploratory question 1 – Demographic Differences Between Groups

An analysis on the participant populations was conducted using the demographic variables of height, weight, race, sex, ethnicity, and time post injury, and injury severity to assess for significant differences (Table 1). All significant results are listed below. Differences between groups not indicated below were found to be not significant.

Comparing Demographics between High and Not High Blood Pressure Groups

When comparing demographics between high and not high blood pressure groups, the results indicated a significant differences in mean height $t(103)=2.27$; $p=0.025$ within blood pressure groups such that individuals with high blood pressure (M=68.53 inches) were taller than those with not high blood pressure (*M*=66.69 inches).

Results also indicated significant differences in weight $t(78.43)= -0.58$, $p<0.001$, between blood pressure groups such that individuals with high blood pressure (M=205.5 lbs) had larger weight values than those in the not high blood pressure group (M=169.28 lbs).

Comparing Demographics between TBI and Healthy Control Groups

When comparing demographics between TBI and healthy control groups Gender populations were significantly different between TBI and Control groups $X^2(1, N = 126) =7.64$, $p< .05$. Less females were represented in Healthy Control (N=15) than TBI Groups (N=27).

Comparing Demographics between all Four Test Groups

Gender populations were also significantly different between High BP - TBI and Not High BP - TBI groups $X^2 (1, N = 126) = 6.78$, $p<.05$). More females were represented in Not High BP – TBI (N=22) than the High BP – TBI (N=5).

Finally, gender populations were significantly different between High BP - TBI and High BP - Control $X^2 (1, N = 126) = 6.50$, $p< .05$. More females were represented in High blood pressure control group (N=6) than high blood pressure TBI group (N=5).

Exploratory question 2 – Assessing the Interaction of TBI and Hypertension on Executive Functioning within only Females and only Males

Further analysis was conducted by stratifying participant population by gender. More specifically, the participant populations were separated by male and female participants.

Following the separation, the same procedure was used to investigate interaction effects of TBI and hypertension on executive functioning. Less females were represented in Healthy Control (*N*=15) than TBI groups (*N*=27) (Table 1). There were no significant differences in male participant populations between groups.

When studying male populations, no significant interaction between hypertension and TBI was detected across the three executive functioning domains. When studying female populations, a significant interaction was found between TBI and hypertension when studying Digit Span Forward data $X^2(1, N = 126) = 7.64$, $p < .05$. Post hoc analysis revealed significant performance deficits in TBI-High BP participants (M=8.48) compared to healthy control-High BP (*M*=12.54). However, this trend was not indicated between TBI (*M*=8.92) and healthy control groups (*M*=9.64) with Not High BP. Additionally, no significant interaction was found between TBI and hypertension when studying Digit Span Backwards, Verbal Fluency FAS, nor TMT Form B/A.

Analysis of Normality

To analyze normality in data distributions, a Shapiro Wilks Test of Normality was performed. The results indicated that Letter Fluency Raw Data did not significantly deviate from a normal distribution ($p>0.05$) (Table 3).

The results indicated that Digit Span Forwards Total, Digit Span Backwards Total, Trails B/A T-score had significant ($p<0.05$) values. In other words, within these distributions the data significantly deviated from a normal distribution (Table 3).

Discussion

The purpose of this study was to better understand the influence of multiple factors on cognitive decline. Specifically, the study focused on the interaction between hypertension, two or more years post injury, and TBI on long-term executive functioning decline.

Hypothesis 1: Main Effects of Blood Pressure on Executive Functioning

A primary finding in this thesis was that blood pressure has a significant affect on certain domains of executive functioning. This was indicated by the significant main effect of hypertension on TMT B/A T-score. TMT B/A T-scores a measurement of attention and inhibitory control - a domain of executive functioning. This shows that lower cardiovascular health (presence of hypertension) was associated with greater attention and inhibitory control deficits. However, hypertension did not significantly impact Digit Span Forward, Digit Span Backward, or Letter Fluency FAS performance. This shows that hypertension was found to only affect one domain of executive functioning – inhibitory control. These results support previous literature that show that systemic hypertension affects inhibitory control and shifting components of executive functioning. Some studies indicate a significant influence of hypertension on phonemic verbal fluency scores (Moraes et al., 2019).

However, results relating to verbal fluency performance within this study may have been influenced by the gender differences within groups given that women have been found to a have a slight advantage in phonemic fluency (Scheuringer et al., 2017). Given that there was a larger

proportion of females in the not high blood pressure group (N=31) compared to those in the high blood pressure ground (N=11), performance in the not high blood pressure group may have been influenced by a slight phonemic fluency advantage. Nevertheless, these results are important because it increases the generalizability of previous studies results to specifically Pennsylvania population.

Hypothesis 2: Main Effects of TBI on Executive Functioning

The main effect of TBI was significant in affecting working memory and verbal fluency (Table 2). This was indicated by a significant main effect of TBI on Digit Span Forward, Digit Span Backward, and Letter Fluency FAS. Digit Span Forward and Backward measured working memory, and Letter Fluency FAS measured verbal fluency (Table 2). Therefore, presence of TBI was found to be associated with working memory and verbal fluency deficits. These results are important because they support previous literature that indicate significant executive functioning performance deficits post-TBI (Ozga et al., 2018). Given the present study used a population sample localized to Pennsylvania, this increases the generalizability of previous studies' results which show a negative relationship between presence of TBI and executive functioning. However, this study present study found that TBI was not significant in affecting attention and mental flexibility measured by Trail making test. This was also supported by Ozga et al. (2018) who found that TBI participants had error and reaction times comparable to non-TBI participants.

One confound that may have influenced the significance levels of TBI on Digit Span measures may have been motivation level of the population. According to Ozga et al. (2018)

some researchers have found that while testing for Digit span as part of the Weschler Adult Intelligence Test battery the presence of motivation influencing results. More specifically, they noted the influence of long and repetitive measurements on the motivation for TBI participants to continue potentially - resulting in lower scores. This indicates that motivation may have influenced the present study's significance levels. However, if motivation is significantly different in TBI versus healthy control participants and significantly affects executive functioning outcomes, motivation may also serve as a mediator explaining one reason why the TBI and working memory are correlated. However, because this battery did not directly assess motivation, more research would need to be conducted to understand the influence of motivation on the relationship of TBI and Digit Span task within Pennsylvania populations.

Hypothesis 3: Interactional Effects between TBI and Blood Pressure on Executive Functioning

The results of the present study also showed an interaction between TBI and hypertension with Digit Span Forwards. In other words, cardiovascular health (measured by the level of blood pressure) affected the nature of the interaction between TBI and working memory (Table 2). More specifically combined effects of hypertension and TBI caused greater executive functioning deficits than solely one condition or no conditions. Post hoc analysis indicated that there were significant performance deficits in TBI compared to Healthy Control groups with High Blood pressure. However, there was no significant performance deficit in TBI compared to Healthy Control groups with Not High BP. This indicates that Blood pressure changed the significance level between TBI and Healthy Control groups enhancing the deficits. Given that

there was not a significant interaction between other measures of executive functioning, TBI and hypertension may only show a significant interaction with working memory – component of executive functioning.

One interesting finding was the difference in significance levels between the interactional effect of TBI and hypertension on digit span forward and digit span backwards (Table 2). While these two tasks measure the same construct of working memory, the interaction between TBI and hypertension had a significant effect on digit span forward performance but not digit span backwards. Studies have shown that performance is typically worse in backwards verbal span tasks rather than forwards. According to a review conducted by Donolato et al. (2017), they found that studies often showed that backwards recall was more influenced by increased recency effect and decreased primacy effect. This contrasted forward visuospatial tasks that contained both primacy and recency effects. This may indicate that the way that the information is incorporated may influence participant performance. Therefore, given that these studies show that healthy individuals have a deficit in backwards recalled when compared to forwards, the differences between groups with pre-existing conditions when assessing backwards recall performance may be less compared to the differences between groups when assessing forwards recall performance. The review also indicated that backward recall was largely found to be associated with a higher level of activation in areas of the brain requiring higher cognitive control. These areas included the right dorsolateral pre-frontal cortex, frontal eye field, frontal operculum cortex, anterior insular cortex, and dorsal anterior cingulate cortex (dACC). One study within the review also found that the activation of the dACC was negatively associated with forward span tasks. According to Bush et al. (2001), the dACC may help to guide behavior by integrating information that assesses motivation, anticipated events, detecting targets,

encoding rewards, and understanding signal errors. If this is true, researchers indicated that this may affect attention. In the context of digit span tasks, if the previous research is true, digit span backwards may require a greater level of evaluation and anticipation. This may result in increased allocation of attention and activation of the dACC. This may be due to a deficit in memory aiding mechanisms such as the primacy effect. As a result, digit span backwards may require more compensatory mechanisms within the brain and attention than digit span forwards, resulting in similar performances among the different conditions while performing digit span backwards tasks. However, the study also prefaced that there is little consensus on a specific model assessing these differences. Therefore, more replication studies need to be conducted to accurately assess the neuronal correlates underlying this difference in significane level between digit span forwards and digit span backwards.

Exploratory question 1 – Demographic differences between groups

When assessing for demographic differences between participant groups, there were significant height and weight differences between those with high blood pressure compared to those without (Table 1). More specifically, participants with high blood pressure were significantly taller and weighed more than those without high blood pressure (Table 1). Current studies show that greater height was associated with lower systolic blood pressure, pulse pressure and greater diastolic blood pressure (Bourgeois et al., 2017). Because this study assessed hypertension in terms of systolic and diastolic blood pressure together, other studies might assess these constructs of blood pressure separately given its differing relationship with height. Studies on weight similarly show the prevalence of hypertension in men and women increasing as body mass index (BMI – a measure describing height and weight) increases. Therefore, this study supports previous studies showing higher weight associated with hypertension. Given that

hypertension had a significant main effect on mental flexibility (as measured by TMT Form B/A T-score) and verbal fluency (as measured by Verbal Fluency FAS scores), height and weight may affect these scores as well. Current studies have assessed the relationship between obesity (as measured by BMI) and executive functioning decline. In a review conducted by Favieri et al. (2019), they found that participants with obesity had more cognitive flexibility deficits, lower inhibitory control, working memory, decision making and processivity. However, they pointed out that directionality of this relationship between executive functioning and obesity was not clear implying a potential reciprocal influence. Given this study and the relationship between hypertension and BMI, future studies may investigate if hypertension is a mediator in the relationship between increasing BMI and executive functioning decline.

Exploratory question 2 – Assessing the Interaction of TBI and Hypertension on Executive Functioning within only Females and only Males

Given the significant main difference of females between the participant groups, the study conducted an exploratory analysis to see if separating female and male participants resulted different significance values. The results indicated that there were no significant interactions between TBI and hypertension on any of the three executive functioning domains. However, there was a significant interaction between TBI and hypertension on Digit Span Forward performance which measured working memory. Given that an interaction in the aggregate data including both females and males showed a similar significant interaction on Digit Span Forward, but not in other tests of executive functioning, results of the aggregate data may be influenced by female participants.

However, such analysis should be made cautiously given the differences in participant numbers. Post hoc analysis on female participants indicated a significant deficit in TBI-High BP

participants when compared to Control-High BP participants, but not when comparing other combinations of Control, TBI, High BP, and Not High BP groups. However, there were a greater number of female participants in the Control-High BP (N=6) than the TBI-High BP (N=5) (Table 1). Additionally, the number of female participants is very low between these groups. Therefore, it is likely that these female participants are not representative of all females in Pennsylvania with High blood pressure. For this reason, more studies with larger female populations need to be assessed to accurately determine the interaction between hypertension and TBI only on female populations. Yet, studies have shown that hypertension is less prevalent in women than men until their 60s (Gillis & Sullivan). Therefore, age may be an important factor when choosing participants and considering the effects of hypertension.

Limitations and Confounding Factors

One potential threat to the construct validity of the independent variables can be that the TMT Form B does not actually measure executive functioning of participants. For example, because TMT Form B requires an individual to draw a line between a series of numbers and letters, it may rather test their visual ability to draw straight lines. Therefore, the errors, or the inability to draw a line connecting two circles, may be a result of their visual acuity deficits rather than attention. Yet, this threat is unlikely as many studies have validated the use of TMT Form B to test executive functioning/cognitive outcome. For example, a study conducted by Sumiko et. al. (2007) analyzed the neuronal activity in the prefrontal cortex (PFC) during the TMT Form A and B. This study used 41 health volunteers who were health, right-handed, and medication free. To measure neuronal activity, they used multichannel near-infrared

spectroscopy to measure oxygenated hemoglobin (oxyHb). Performance was evaluated using TMT Form A and Form B during spectroscopy evaluation. The study found that there was activity in the PFC during TMT Form B. This provided evidence that TMT Form B involved the prefrontal cortex which regulates executive functioning. Therefore, this supports the notion that TMT Form B measures executive functioning (Shibuya-Tayoshi et. al., 2007).

Another limitation to this study was the fact that the presence of hypertension at the time of injury was unknown. Although presence of hypertension at the time of TBI occurrence was not known, this may be more reflective of real-world limitations seen by clinicians. More specifically physicians may not have records on hypertension in patients pre-TBI or at the time of impact multiple years after injury.

A potential confounding factor that can threaten internal validity could be age. Individuals that are older may be more likely to have executive functioning deficits skewing results. For example, according to Obisesan et. al. (2008), they found that individuals above 70 had higher BP and poorer cognitive function. But given that this study analyzes participants within a strict age range from middle to late adulthood, this risk of age influencing data will be controlled. Additionally, this study differentiates those with high BP and Not High BP. Therefore, it is likely that people above 70 without high BP will also be represented.

A second confound may have been intelligence. Studies have shown that early education of up to 8 years can promote successful childhood development. This can help to protect against cognitive decline in late life (Xahodne et al., (2015). Other studies have shown that educational attainment influences cognitive function later in life by contributing to cognitive skills that occur in early adulthood and are carried out into later adulthood (Lövdén et al., 2020). Therefore, cognitive functions within the study may have been influenced by educational ability.

Additionally, this study may not be generalizable to populations who are not white due to the over representative within the sample. This is because there were very few Hispanic or Latino participants, African American participants, and no participants who were Asian or Pacific Islanders. Studies have shown that racial/ethnic minorities are at an increased risk for TBI and poorer outcomes post-TBI. Some studies indicate that American Indian/Alaska Natives had the highest annual TBI-related mortality rates followed by African Americans. Some factors that contribute to their poorer cognitive outcomes are other aspects of health such as insurance status (Gao et al., 2018). Therefore, this shows that future studies must be conducted on diverse populations while also taking into account other factors such as insurance status when assessing cognitive outcomes.

Finally, after conducting a Shapiro Wilks test of normality, the distributions of scores for Digit Span Forward, Digit Span Backward, and Trails B/A T-score (Table 3). Therefore, these distributions may not serve to describe many populations decreasing its generalizability. However, this further underlines the importance of conducting research among different participant populations to better understand influencers of executive functioning decline.

Importance and Future Applications of the Study

Even with these confounds and limitations, this study is important because it provides a basis for future studies on cognitive decline. Future studies can investigate the neuronal development causing these associations. For example, Son et. al. (2015) investigated the relationship between hypertension and functional connectivity to explain the correlation between hypertension and cognitive decline. The objective was to better understand the effects of

hypertension on resting state functional connectivity in patients with Alzheimer's disease. The independent variable had two levels – hypertensive and non-hypertensive. The dependent variable was the resting state functional connectivity. They found that there was decreased connectivity to the PCC in regions of the left subgenual anterior cingulate cortex (ACC) in hypertensive groups. There was also an increased connectivity to the PCC in the left inferior parietal cortex in hypertensive groups. These results were important because they attempted to explain a phenomenon that occurs in hypertensive patients. Therefore, by integrating the results of their study with the results of this present proposal, future studies can investigate the functional connectivity differences associated with the potential comorbidity of hypertension and cognitive decline in executive functioning.

Additionally given the low representation of females, future research could count for more data on females. This would increase the validity of the results of this study. Similarly given the low representation of ethnic minority populations, future studies may choose to assess participants form different locations throughout Pennsylvania to attain a more representative sample. However, this study provides a basis and model from which future studies can be developed.

Results from this and future studies can also provide a basis for future treatments in connectivity to decrease the effects of cognitive decline in hypertensive patients with TBI. This can also help physicians in their treatment for cognitive decline post TBI. By identifying the potential interaction between TBI and hypertension, physicians can focus treatment of hypertension in TBI affected patients. It may also help scientists to discover buffers between TBI and cognitive decline. By doing so this may help physicians in prescribing prognoses and advising preventative measures to patients with TBI. This will help to prevent TBI related

disabilities such as cognitive decline and potentially delay the onset of cognitive diseases such as Alzheimer's Disease. As a result, this research can help decrease the large number of individuals affected by age related cognitive diseases in America.

Figure 1

Interaction between blood pressure and TBI on Executive Functioning measures.

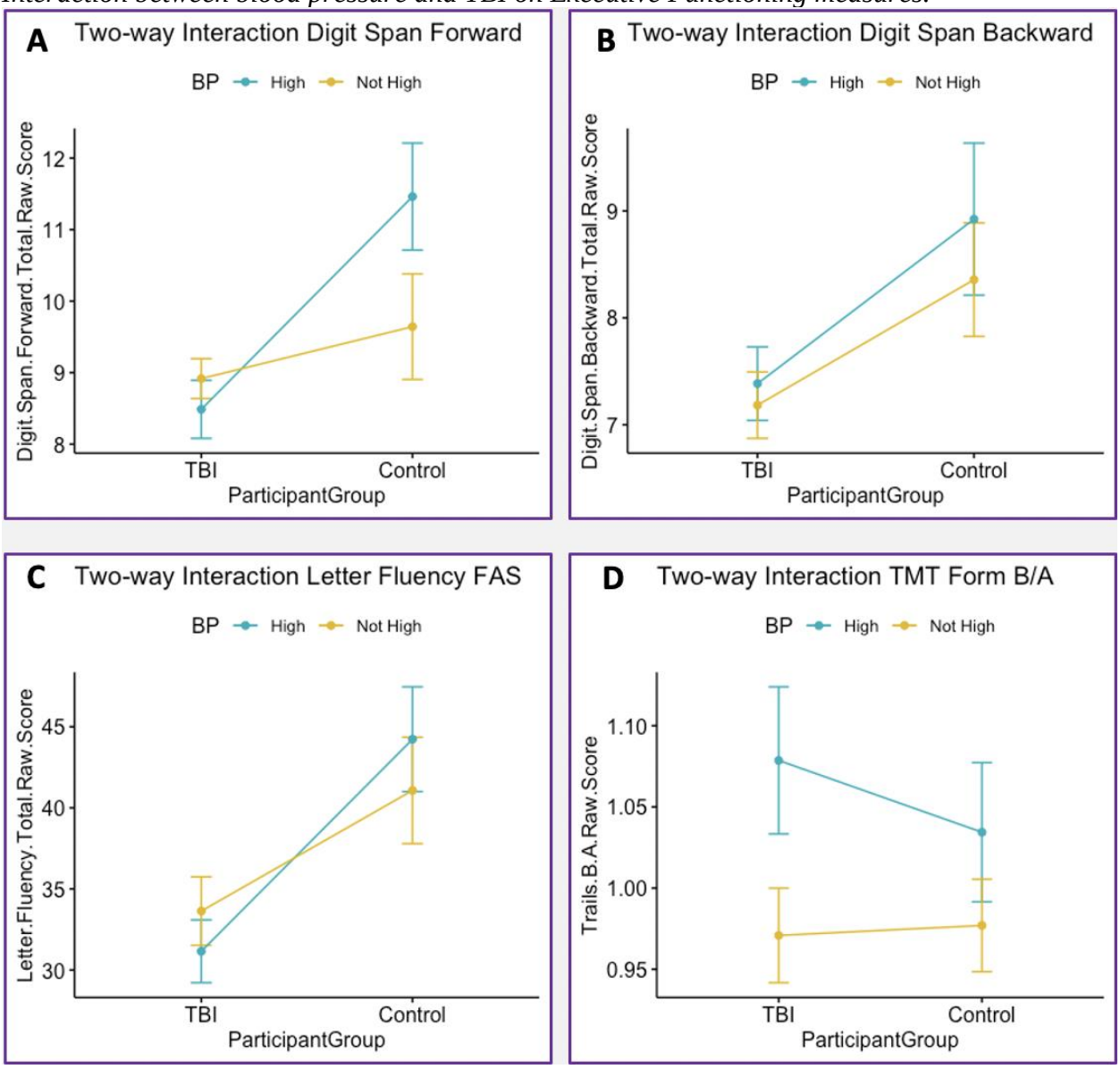

Figure 1. (A) Line plot shows Digit Span Forward Raw score distribution. (B) Line plot shows Digit Span Backward Raw score distribution. (C) Line plot shows Letter Fluency Score (FAS) distribution. (D) Line plot shows TMT B/A Score distribution.

Table 1

Breakdown of Participant Demographics

Characteristic	**Healthy Control**				**TBI**			
	HC-H (N = 12)		**HC-NH (N=14)**		**TBI-H (N = 39)**		**TBI-NH (N=60)**	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Height (Inches)	66.46	4.33	66.57	4.33	69.13	4.24	66.71	4.07
Age	63.77	6.38	61.93	7.41	64.31	6.86	64.02	8.89
Time Post Injury (Years)					8.61	6.26	9.31	5.40
Weight	185.15	34.75	176.79	32.26	211.44	58.02	167.47	38.12
Sex	7 Males, 5 Female		5 Male, 9 Female		34 Male, 5 Female		38 Male, 22 Female	
Race	6 Caucasian, 6 African-American		12 Caucasian, 2 African-American		30 Caucasian, 9 African-American		47 Caucasian, 13 African-American	
Ethnicity	12 NOT Hispanic or Latino		14 NOT Hispanic or Latino		36 NOT Hispanic or Latino		44 NOT Hispanic or Latino, 4 Hispanic or Latino	
Injury Severity					22 severe, 9 moderate, 8 mild		37 severe, 12 moderate, 11 mild	

*Ethnicity missing for N= 15

*Time post injury missing for N = 28

Table 2.

Executive Functioning Data

Executive functioning metrics	**N**	***p* - value**	**η^2**	**F-test**	**95% CI**
Digit span forward raw	126				
TBI		<.001***	.083	F(1,125)=11.52	[-2.138, 0.686]
Blood Pressure		.87	.00019	F(1,125)=0.025	[-0.0139, 3.65]
Interaction		.034.	.033	F(1,125)=4.59	[-4.33, -0.17]
Digit span backward raw	126				
TBI		.0072**	.058	F(1,125)=7.48	[-2.53, 0.18]
Blood Pressure		.50	.0035	F(1,125)=0.46	[-1.19, 2.32]
Interaction		.72	.0010	F(1,125)=0.13	[-2.35, 1.63]
Letter Fluency Raw	126				
TBI		.0017**	.077	F(1,125)=10.25	[-15.84, 0.96]
Blood Pressure		.64	.0017	F(1,125)=0.22	[-7.74, 14.06]
Interaction		.37	.0061	F(1,125)=0.82	[-17.99, 6.72]
Trails B T-score	124 (2 NA)				
TBI		<.001***	0.20	F(1,123)=29.82	[-21.30, -8.29]
Blood Pressure		0.57	.0021	F(1,123)=0.32	[-10.25, 6.60]

Interaction		0.43	.0042	F(1,123)=0.63	[-5.74, 13.41]
Trails A T-score	124 (2 NA)				
TBI		<.001***	.20	F(1,123)=29.50	[-20.52, -7.93
Blood Pressure		.24	.0093	F(1,123)=1.41	[-12.79, 3.52]
Interaction		.52	.0027	F(1,123)=0.41	[-6.28, 12.26]
Trails B/A T-Score	124				
TBI		.87	0.00023	F(1,123)=0.029	[-0.14, 0.13]
Blood Pressure		.022*	.043	F(1,123)=5.36	[-0.12, 0.23]
Interaction		.61	.0020	F(1,123)=0.26	[-0.15, 0.25]

*p<0.05

Table 3.

Shapiro Wilks Test of Normality

Test	P-value
Digit Span Forwards Total	0.0013*
Digit Span Backward Total	<0.001*
Letter Fluency Raw Score	0.20
Trails B/A T-score	0.0044*

*p<0.05

Appendix A

Copies of battery tests could not be provided due to copyright and the ongoing nature of the studies utilizing the battery tests. Below is a list of the tests utilized as well as their publishing companies if applicable.

Table 4.

List of Cognitive Tests and Publishing Companies if Applicable

Cognitive Test	Publishing Company
WAIS-IV Digit Span Forward & Backward	Pearson Publishing
Verbal Fluency Test FAS	Pearson Publishing
Trail Making Test A & B	

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ACADEMIC VITA

ADWAIT CHAFALE

EDUCATION

The Pennsylvania State University – *University Park, PA* Spring 2022
B.S. Psychology; Concentration: Neuroscience; Minor: Biology

HONORS & AWARDS

2021 Scholar Involvement Award - *University Park, PA* Fall 2021
Dean's List - *University Park, PA* Fall 2018 – PRESENT
Academic Excellence Scholarship - *University Park, PA* Fall 2018 – Fall 2021
Schreyer Honors Scholar - *University Park, PA* Fall 2018 – PRESENT
Scholar Alumni Society Future Leaders Scholarship - *University Park, PA* 2020-2021
Learning Assistant Award for Teaching excellence in Physics - *University Park, PA* 2020-2021
Pennsylvania High School Persuasive Speech Competition Finalist – *Berwyn, PA* 2017-2018

MEDICAL & RESEARCH EXPERIENCE

Clinical Neuropsychology Lab (Dr. Frank Hillary) – *University Park, PA* January 2019 – PRESENT

- Undergraduate research assistant currently executing and presenting a study analyzing the effects of Blood pressure on the relationship between traumatic brain injury and decline in executive functioning using RStudio.
- Previously examined and presented the neurological effects of traumatic brain injury on semantic memory through the application of behavioral tests, RED Cap database usage and entry, and other statistical measures.
- Collected/organized reports on over 100 cognitive developments following traumatic brain injuries.

The Hancock Lab– *University Park, PA* May 2020 – September 2020

- Summer undergraduate research assistant studying the local and global effects of kinesin binding on microtubules such as those found in neurons
- Utilized MATLAB, Gillespie algorithm, Poisson distributions, and Michaelis Menten based kinetics to successfully quantify the probabilities in global effects of microtubule expansion/compaction.

Penn Medicine – *Philadelphia, PA* May 2019 - June 2019

- Shadowed for over 150 hours under Dr. Benjamin Chang - orthopedics and plastic surgery of the hand.
- Observed various surgical procedures on the lower arm extremity treating congenital defects and injuries.
- Wrote a comprehensive study guide on hand surgery and anatomy to be used for medical students

Paoli Surgery Center – *Paoli, PA* May 2018 - July 2018; July 2019

- Visually examined procedures for over 400 hours within this center specializing in orthopedic surgery, ENT, plastic surgery, oral/maxillofacial surgery, and podiatry.

LEADERSHIP & SERVICE

Multicultural Association of Schreyer Scholars - *Peer-to-Peer Director* January 2019 - PRESENT

- Worked with and developed an Assistant Dean of Diversity and Inclusion position in the Honors College.
- Collaborated directly with honors college staff on policies enhancing diversity at Penn State with a select board.
- Organized/conducted student trainings on Cultural Competency and Microaggressions for over 200 students.
- Executed the first initiative pairing 250 new & current Schreyer Scholars across PA fostering communication.

SHO TIME New Student Orientation – *Team Leader 2020 & 2021, Mentor 2019* 2019-2021

- Helped organize the first synchronous virtual/in person orientation that incorporated the commonwealth campuses for 300+ incoming Schreyer Scholars.

- Created a successful communications campaign using biweekly newsletters and effectively using social media platforms such as Instagram, Twitter, and Facebook to communicate.
- Developed a program for 200+ Schreyer Scholars to engage with and learn from the broader State College, PA, community. Included over 10 different civic engagement projects developed by Scholars.

Peer-Health Educator September 2020 – December 2021

- Facilitated diverse one-on-one services on sexual wellness/relationships, stress, and nutrition.
- Created Social media content on healthy lifestyles for college students for platforms such as Instagram.
- Developed seminars to educate students on minority health issues.

Remote Area Medical September 2018 – December 2021

- Elected onto Clinic Outreach Team organizing the first RAM free healthcare clinic in Pennsylvania.
- Volunteered at various free clinics across the United States assisting medical professionals and patients.

ReGeneration - *Vice-President* January 2019 – May 2021

- Created safe spaces/groups for students with mentally ill loved ones for support and advice through guest lecturers.
- Increased advocacy for House Bill 18 on mental health through direct communication with lawmakers.
- Developed virtual resources on Mental Health for diverse individuals including veterans and immigrants.

Physics 250 - *Learning Assistant* January 2020, 2021

- Received a Learning Assistant Award for Teaching excellence in Physics to 200+ students.
- Developed metacognitive studying resources and free personalized study tactics sessions for students.
- Integrated individual cultures into tactics to decrease adversities affecting students' quality of work.

PRESENTATIONS

"Investigating Cerebral and Cardiovascular Interactions Underlying Cognitive Decline."

- 2021 Undergraduate Exhibition for Research, Inquiry, or Creative Activity, Online, April 2021

"Effects of Hypertension and TBI on Executive Functioning in Middle-to-Late Adults."

- Psi Chi Research Conference, Online, April 2021

"Effects of traumatic brain injury (TBI) severity on semantic memory retrieval one year or more post TBI."

- 2020 Undergraduate Exhibition for Research, Inquiry, or Creative Activity, Online, April 2020