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Sex Difference Regarding White Matter Integrity Influencing Cognitive Function Post-TBI

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ABSTRACT

Traumatic brain injury (TBI) affects millions of Americans each year. TBI leads to many short and long term consequences, with moderate to severe often resulting in lasting cognitive impairment. The role of white matter (WM) integrity measured by fractional anisotropy (FA) is an important aspect when determining the severity of cognitive deficits post-TBI. Past studies have noted that WM structure is largely variable based on sex. Given this background, WM integrity could have differential impact on cognitive performance based on sex. After analysis, it was found that the TBI group had lower mean FA values than the HC group. However, when separating by sex, there was no significant difference between male and female FA values for either TBI or HC group. FA was significantly correlated with every neuropsychological assessment administered, however the effect sizes for different facets of cognition varied. FA had the smallest effect size for measures of memory and the largest effect sizes for measures of processing speed and sustained attention. In the future, FA values may be used as useful tools to determine the extent to which an individual with TBI is impacted by deficits in specific areas of cognition.

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Introduction

Traumatic Brain Injury

Traumatic brain injury (TBI) impacts 1.5 million individuals each year in the United States (Langlois et al., 2006). There exist many immediate negative consequences of TBI, including loss of consciousness, muscle spasticity, and memory impairments (American Congress of Rehabilitation Medicine, 1993). Long-term impairment due to TBI are also common. Cognitive processes impacted long term post-TBI include processing speed, attention, executive functioning, and episodic memory (Wortzel & Arciniegas, 2012). These impairment often contribute to emotional distress, providing obstacles to completing many activities of daily living (DeLisa et al., 2005).

Mild, moderate, and severe TBI have associated levels of complications during the recovery process. In moderate and severe TBI, individuals have clear impairment at the 1 month post-injury timepoint (Boake et al., 2001). Impairments lasting more than 3 months are an indicator of chronic disability (Skandsen et al., 2010). Brain function typically returns to baseline functioning within 3 months for mild TBI, however moderate and severe TBI can prevent normal brain functioning even after 2 years post-TBI (Schretlen et al., 2003).

Neuropsychological testing has been shown to be an accurate measure of the severity of TBI, as well as which cognitive domains have been impacted by TBI (Prince & Bruhns, 2017). The goal of neuropsychological evaluations are to determine both the functional and cognitive deficits of an individual after they have sustained an neurological injury. Within these

assessments, neuropsychological batteries are administered to measure different aspects of functioning. There are a variety of assessments, each one aimed at measuring different facets of cognitive function. Individuals with severe TBI will typically be given a battery that is shorter and easier to complete, as the severity of their injury makes their deficits easier to detect. Conversely, those with mild to moderate TBI are typically given more a more exhaustive battery, as their deficits more subtle and harder to detect (Lezak et al., 2004). These batteries provide valuable quantitative data to measure the extent to which TBI has impacted their functioning.

These assessments also include an interview to gather qualitative information about both the patient's premorbid and post-TBI personality characteristics, behaviors, and factors regarding psychological history that could contribute to the current clinical presentation. This holistic model of evaluation is essential for diagnoses, creating treatment, monitoring recovery, and research.

Sex Differences

Sex-mediated neuroanatomical differences have long been observed, with some of the most robust and repeatable findings including a volumetrically larger male brain (Ruigrok et al., 2014) and neuronally denser female brain (Luders et al., 2004). However, recent studies have allowed a more nuanced view of these sex-mediated neuroanatomical differences. Region-specific models of grey matter density have demonstrated that females typically have greater GMV in the medial PFC, lateral PFC, orbitofrontal cortex, superior temporal, lateral parietal cortex, and insula. Males typically have greater GMV in the ventral temporal and occipital regions, temporal pole, fusiform gyrus, primary visual cortex, hypothalamus, BNST, amygdala, hippocampus, putamen, and cerebellum (Liu et al., 2020). Additionally, there is evidence to

suggest that male and female white matter structures are significantly different, with differences that, without accounting for sex-mediated structure differences, would be considered pathological (Kanaan et al., 2012).

White Matter

WM integrity is essential for proper cognitive functioning. WM connects regions of the brain, allowing for proper communication within the brain. After TBI, damage to WM tracts can disrupt these connections, leading to deficits caused not by the inability to generate neural signals, rather the inability to effectively transmit them (Bigler, 2001). Damaged WM has been demonstrated to impair executive functioning and memory (Mesulam, 1998).

Damage to WM tracts has been difficult to study with CT and traditional MRI (Rugg-Gunn et al., 2001). Conventional MRI is able to detect microbleeds which can be used to indicate diffuse axonal injury (Scheid et al., 2003). However, the complex structure of WM tracts is unable to be appreciated with this type of MRI. The introduction diffusor tensor imaging (DTI), however, has allowed for a higher resolution view of WM.

Basics Conception of MRI

MRI functions by detecting the motion of hydrogen atoms. Therefore, the MRI can be elementarily conceptualized as imaging tissue based on differing water contents. The MR machine generates an electric field and the hydrogen atoms align themselves with this field. The hydrogen atoms spin around their own axes, each proton in the same phase. Then, a radiofrequency (RF) wave is shot at the protons, disrupting the uniform spinning and phase of each proton. Then, an RF wave that is opposite of the first RF wave is shot at the protons for an

equal amount of time, resulting in all the protons returning to a uniform spin and phase. Because each proton is aligned in the same direction, the MRI signal would be bright.

However, this situation would only occur if each hydrogen molecule remained in the same location. However, according to the laws of thermodynamics, molecules are always moving. In the real world, the same initial conditions can be assumed. However, after the first RF wave is applied, the protons will dephase and move in 3D space. Because the protons are in different locations, the second RF wave will not completely reverse the effects of first RF wave, resulting hydrogens that are still spinning in a different phase. Because there are less protons in the same phase, the MRI signal will be less intense. Using this principle, in areas where hydrogen atoms can move more freely, the image will darker, and in areas where hydrogen atoms are more restricted, signal will be brighter.

Details of MRI

Magnetic resonance imaging (MRI) is a type of imaging measures the influence of magnetic fields on protons to generate an accurate representation of the tissue being imaged. The three main variables that determine the structure of the image produced are (1) proton density (PD), (2) longitudinal relaxation time (T1), and (3) transverse relaxation time (T2). PD, T1, and T2 are basic properties of materials when placed in a magnetic field (Halle, 1998; Fullerton et al., 1985; van Zijl et al., 2018) Tissue with high PD appear bright in imaging, typically indicating the presence of a concentrated amount of nuclei (Major et al., 2020). Magnetic resonance imaging (MRI) utilizes powerful magnets to generate a strong magnetic field (B_0). When tissue experiences the influence of B_0, a net magnetization vector, which is the mean of all the magnetic properties of the nuclei present within sample tissue, is created. The protons present in

water molecules are influenced by B_0, being organized in alignment with this field (National Institute of Health, n.d.).

After this, a radiofrequency (RF) wave is pulsed through the tissue in bursts (known as RF-pulses). This RF wave provides energy to the protons, exciting them and increasing the net magnetization vector. This process knocks the protons out of alignment with the magnetic field. After the RF pules, the nuclei lose the added external energy and the time it takes for the protons to return to equilibrium in the magnetic field is measured. The times it takes for the longitudinal factor of B_0 to return to 63% of its initial vector is known as T1.

After the initial RF pulse was sent through the tissue, the net magnetization vector shifts to the transverse axis. This is possible because of phase coherence, which is the phenomenon in which two signals with the same frequency have a constant phase difference. The time required for the two signals to rephase to 37% of B_0 is known as T2 (Bloch, 1953).

An understanding of magnetism is important to understanding MRI. All matter has some sort of interaction with magnetic fields. The degree to which an object interacts with a magnetic field (χ) is expressed in the equation below (Schenck, 1996):

$$\chi = \frac{M}{H}$$

Where M is the intrinsic magnetic quality of the material (magnetic moment/volume) and H is the strength of the magnetic field (ampere/meter). In MRI, the B_0 is measured in Tesla (T), which describes the magnetic flux density. For comparison, Earth's magnetic field is around 0.00005T (U.S. Department of Energy, 2013) while many MRI machines used in a clinical setting are 1.5T or 3.0T.

The electron cloud of a molecule determines its magnetism. Orbitals with more paired electrons leads to a lower χ while orbitals that contain unpaired electrons leads to a higher χ. The

four categories of magnetic objects include ferromagnetic, superparamagnetic, paramagnetic, and diamagnetic objects. Ferromagnetic materials are characterized by their intrinsic strong attraction to magnets (Britannica, 2023) and have a positive χ value typically greater than 100. Superparamagnetic have magnetic attraction much less than ferromagnetic material, but also significantly more than paramagnetic materials. Paramagnetic materials are characterized by a weak attraction to magnets (Britannica, 2023) and have a positive χ value between 10^{-5} and 10^{-3}. Diamagnetic materials align perpendicular to the magnetic field (Britannica, 2023) because they have a negative χ value around 10^{6}.

What can influence MRI?

T1 can best be conceptualized as a thermodynamic process. The RF waves provide energy to the nuclei in the sample, exciting them out of alignment with the magnetic field. However, other factors exist which can influence the speed of the protons. First, a dense tissue provides a barrier to exciting protons. Environments dense with various biomolecules (e.g. fat, proteins, mucus, etc.) provide resistance to the excitement of protons, therefore shortening T1. Additionally, temperature is an important source of thermodynamic energy. The human body's natural resting temperature is 37ºC, providing a specific amount of thermal energy to the nuclei within tissue. Elevations or depressions of this temperature would significantly influence T1. Therefore, tissue with elevated temperatures (i.e., fevers) would provide excess energy to nuclei and elongate T1 while cooled tissue (i.e., tissue analyzed after death) would be absent of the expected environmental thermal energy and have a shortened T1 (Grabherr et al., 2015; Nelson & Tung,1987; Ruder et al., 2012) . Paramagnetic materials can also influence T1 by fastening the protons. The paramagnetic characteristic of certain implants can increase the wobble as the

protons move around a rotational axis (i.e., precession) (My MS, n.d.), providing another avenue to release energy gained from RF pules and shortening T1.

What is DTI?

Diffusor tensor imaging (DTI) is a type of imaging utilizes MR to determine the magnitude, orientation, and degree of diffusion of water. Diffusion describes the passive and gradual three-dimensional movement of water over a period of time. Without boundaries, water will diffuse at an equal rate in all three dimension, creating a spherical diffusion pattern. This pattern of unrestricted diffusion is referred to as isotropic diffusion. However, diffusion within biological systems is influenced by the cellular structure, restricting its ability to isotropically diffuse. For example, in fibrous tissue, water is able to freely diffuse parallel to the orientation of the tissue. However, diffusion is hindered perpendicular to the tissue, as the water is restricted by the cell membrane. This restricted pattern of diffusion is referred to as anisotropic diffusion.

DTI is especially helpful when mapping white matter (WM) tissue. The diffusion of water within healthy WM can be conceptualized as a highway. In healthy WM, water will travel along the axonal highway, being "directed" by the cell membrane of the axon. Therefore, this diffusion is expected to be anisotropic, being highly directional along the length of the axonal tracts. However, if axonal tissue was subject to damage, the diffusion pattern would change. In this case, water would lose its "director", no longer having directions to be able to effectively travel along the axonal highways. This break in the membrane of the axon would allow water to diffuse perpendicular to the WM tract, increasing the isotropic nature of diffusion.

The anisotropic characteristic of axonal tracts allows these measures to determine the structure and integrity of WM (Moseley et al., 1990). When tissue structure or integrity is altered, the pattern of diffusion will reflect this.

The diffusor tensor describes measuring protons in 3D space as well as measuring their vector of diffusion along each axis. This can be modeled using a 3x3 matrix:

$$\begin{matrix} X_x & Y_x & Z_x \\ X_y & Y_y & Z_y \\ X_z & Y_z & Z_z \end{matrix}$$

The largest vector of diffusion is referred to as the principal diffusion direction. In highly anisotropic tissue, this vector serves as a measure to determine the direction of that fiber.

DT images are generated through creating magnetic gradients that are sensitive to only one direction of diffusion. Through repeated generation of magnetic gradients sensitive to different directions of diffusion, a model of diffusion can be generated within the brain.

As stated previously, signal is only detected when hydrogen atoms are oriented int the same direction. The applied magnetic gradients cause water protons in areas of anisotropic diffusion to randomly shift phase, resulting in a loss of signal. Therefore, white matter tracts that run in the same direction as the applied magnetic gradient will generate a darker image.

There are two main categories of measures used to describe diffusion: measures of anisotropy and measures of the magnitude of diffusion.

Diffusion Magnitude Measures:

By simply averaging the vectors of diffusion, the mean vector of diffusion can be found. This is referred to as mean diffusivity (MD). MD acts as a measure of all the diffusion in a specific voxel. This is especially useful in a clinical setting during early detection of stroke.

Cytotoxic edema, which is the swelling of cells, would inhibit diffusion (Schlaug et al., 1997), which would be reflected by a lower than expected MD.

Anisotropy Measures:

Fractional anisotropy (FA) index is one measure to visualize the WM architecture in the brain, with high FA indicating that the diffusion of water is highly directional along the axon tract, reflecting an intact axon. When FA is low, diffusion is isotropic, reflecting damaged axons (Pierpaoli et al., 1996). Mean diffusivity (MD) is another measure of WM integrity indicates the degree to which water can freely diffuse. A high MD value reflects water freely diffusing in tissue and a potentially damages WM tract. A low MD value reflects a restricted pattern of water diffusion, which is what would be expected of healthy WM.

Hypothesis

Due to the significant differences between male and female white matter structure, is it possible that measures such as FA could have differential impact on the cognitive functioning of males and females post-TBI? Given this background, this study aims to determine in moderate to severe TBI patients whether (1) FA values predict performance on different neurocognitive measures, and (2) the effect size different for males and females.

Methods

Participants

32 participants with traumatic brain injury (24 males, mean age ± SD: 63.8 ± 8.2 years) and an age-matched control group of 21 health controls (10 males, mean age ± SD: 64.7 ± 6.9 years) were recruited. Participants were recruited on average 9.0 years post injury (SD ± 7.3 years). Causes of injury included fall (47%), motor vehicle accident (22%), motorcycle accident (13%), pedestrian (9%), bicycle (6%), and winter sports (3%). Patients with neurodegenerative disorders were excluded from analysis.

Behavioral Measures

A neuropsychological battery was administered to each participant. This battery collected data regarding the cognitive functioning of each subject, focusing on the subjects' processing speed and memory. The tests administered include the Wechsler Adult Intelligence Scale Fourth Edition (WAIS-IV) Coding, Digit Span, and Symbol Search, Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) Figure Copy and Story Memory, Trail Making Test B (TMT), and the Visual Search and Attention Test (VSAT). The mean and standard deviation was recorded for data analysis.

Structural Imaging

Each participant was either scanned using a Philips Achevia 3T scanner in the Department of Radiology at Hershey Medical Center, Hershey, PA or using a Siemens Magnetom Trio 3T scanner in the Social, Life, and Engineering Science imaging Center at the

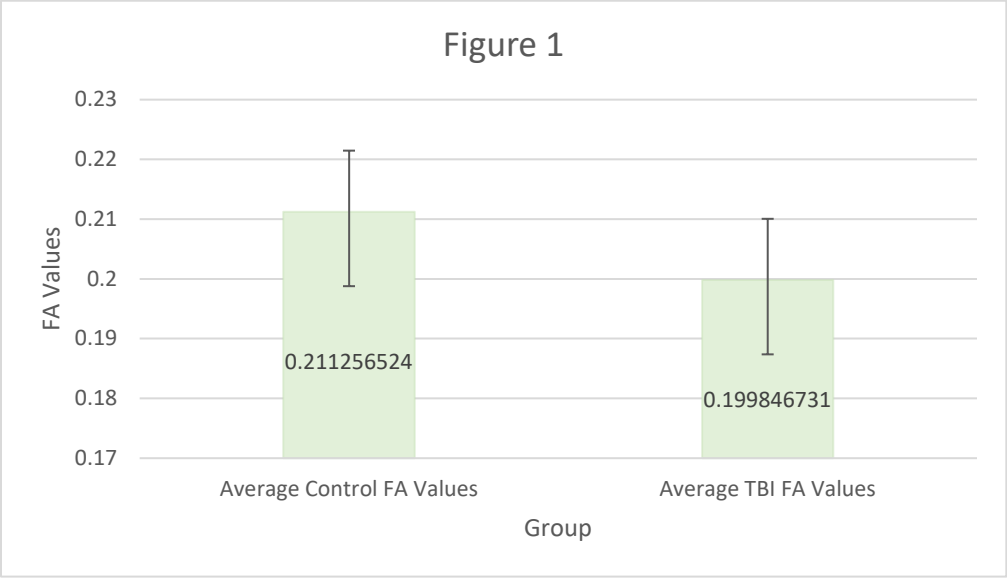
Pennsylvania State University, University Park, PA. MRI images were generated using guidelines determined by previous studies investigating TBI and cognition (Hillary et al., 2010). High-resolution 3D T1-weighted MPRAGE images (9.9 ms/4.6 ms/8^{o} repetition time/echo time/flip angle TR/TE/FA), 240 X 204 X 150 mm3 field of view (FOV), 256 X 205 X 150 acquisition matrix, two averages, were generated.

Analysis of White Matter Structure and Cognitive Function

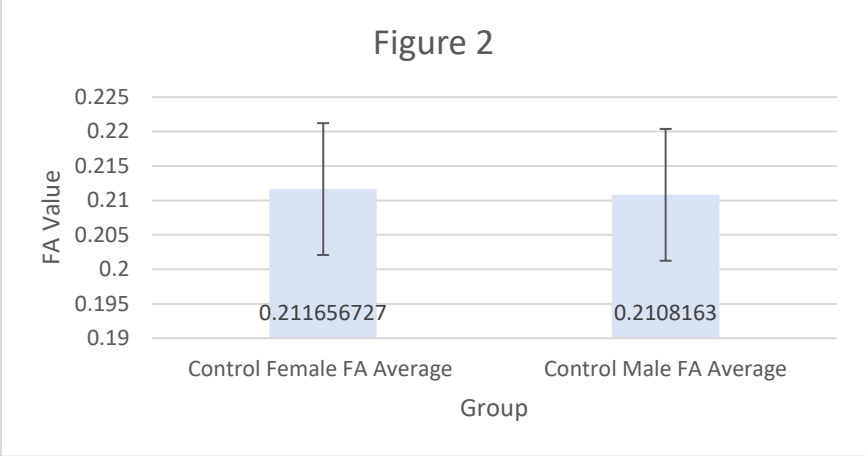
The relationship between white matter structure integrity and cognitive function was investigated. WM integrity was measured with FA values while cognitive functioning was measured via the neuropsychological battery. Correlations were drawn across the control and TBI groups, as well as within each group using sex as a differentiating variable.

Results

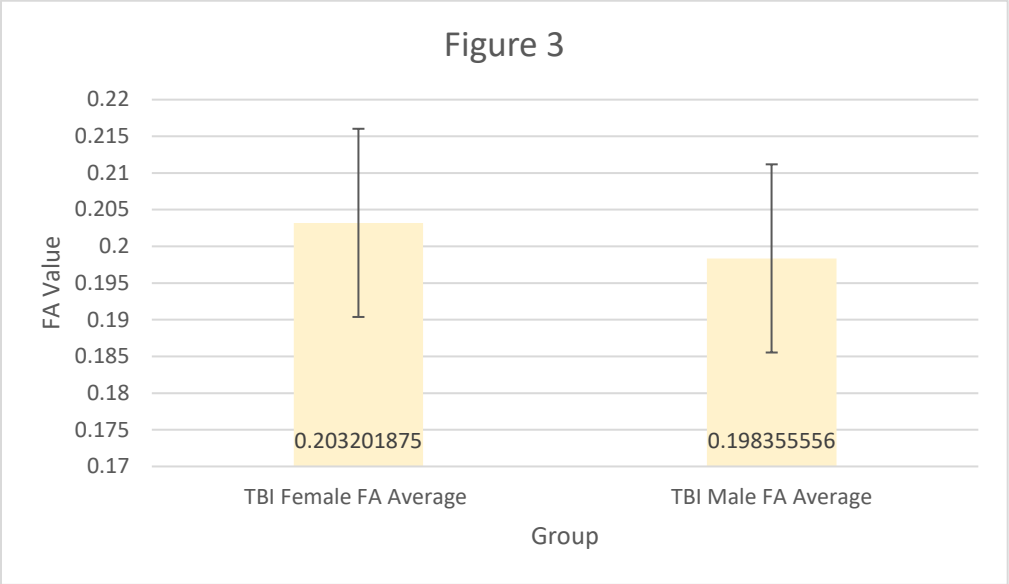
The average FA value for the TBI group was significantly lower than the control group (TBI ± SD: 0.20 ± 0.01; HC ± SD: 0.21 ± 0.01; $p \geq 0.05$). These results are shown in Figure 1.



There was not statistically significant difference between mean FA values in the HC group between males and females (Females ± SD: 0.21 ± 0.01, Males ± SD: 0.21 ± 0.01, $p \leq 0.05$) (See Figure 2).



There was no statistically significant difference between mean FA values in the TBI group between males and females (Females± SD: 0.20 ± 0.01, Males ± SD: 0.20 ± 0.01, $p \leq 0.05$) (See figure 3).



The mean FA standard deviation was not significantly different between the HC and TBI groups (TBI ± SD: 0.17 ± 0.01; HC ± SD: 0.17 ± 0.01; $p \leq 0.05$). The mean FA standard deviation in the HC group between males and females was not significant different (Females ± SD: 0.17 ± 0.01, Males ± SD: 0.17 ± 0.01, $p \leq 0.05$). The mean FA standard deviation in the TBI group between males and females was not significant different (Females ± SD: 0.16 ± 0.01, Males ± SD: 0.17 ± 0.01, $p \leq 0.05$).

Neuropsychological Battery Results

Within the WAIS-IV, FA values were positively correlated with performance on Coding ($R^2 = 0.13$, $p \geq 0.05$), Digit Span Forward ($R^2 = 0.01$, $p \geq 0.05$) Digit Span Backwards ($R^2 = 0.02$, $p \geq 0.05$), and Symbol Search ($R^2 = 0.12$, $p \geq 0.05$) (See Figures 4-6).

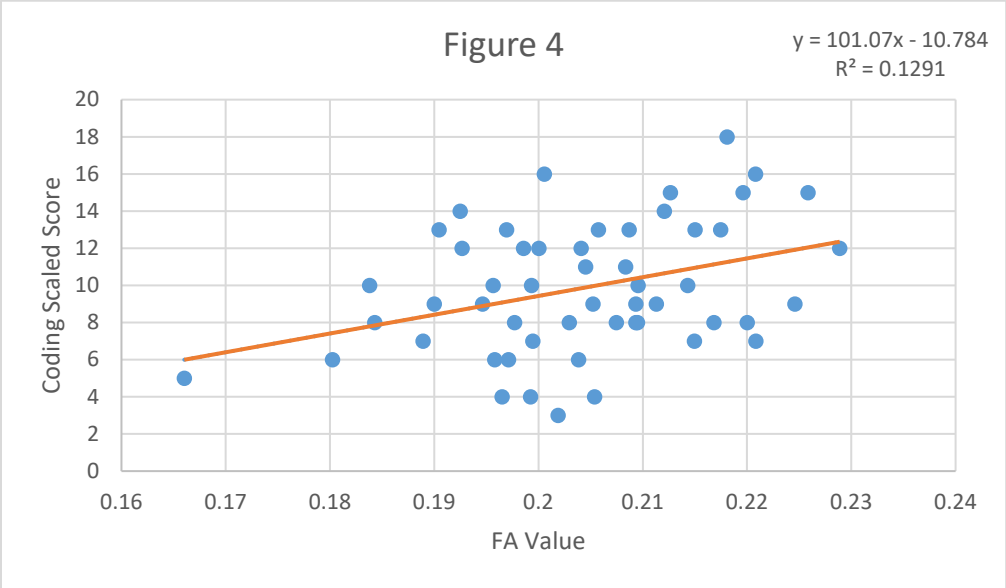


Figure 4
y = 101.07x - 10.784
R² = 0.1291
Coding Scaled Score
FA Value
0
2
4
6
8
10
12
14
16
18
20
0.16
0.17
0.18
0.19
0.2
0.21
0.22
0.23
0.24

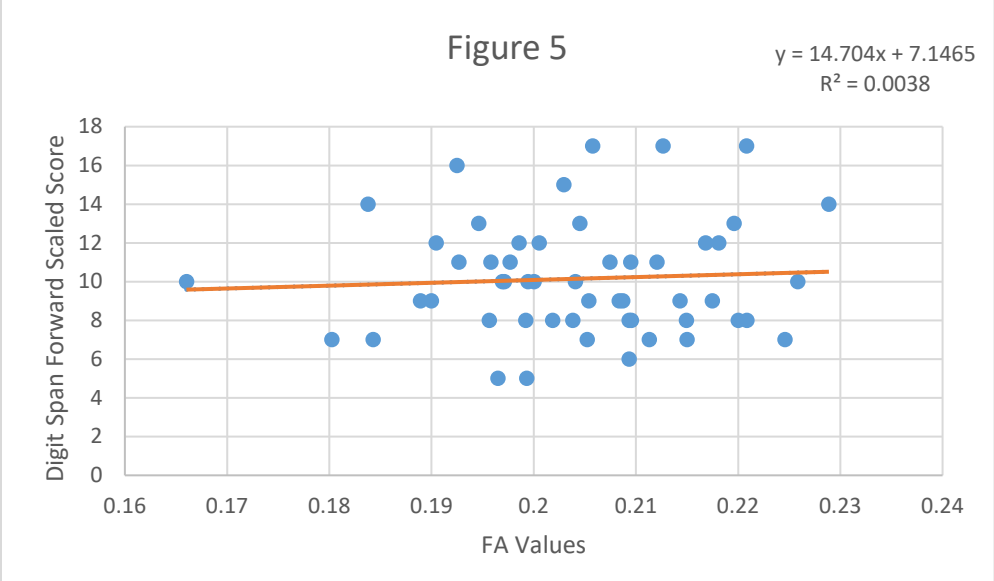
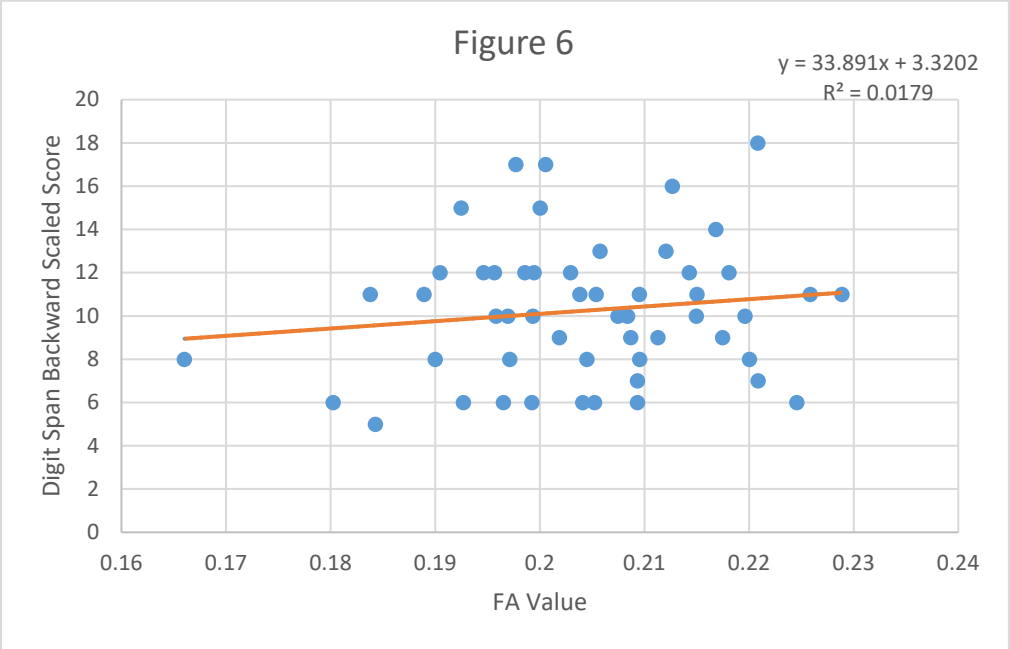
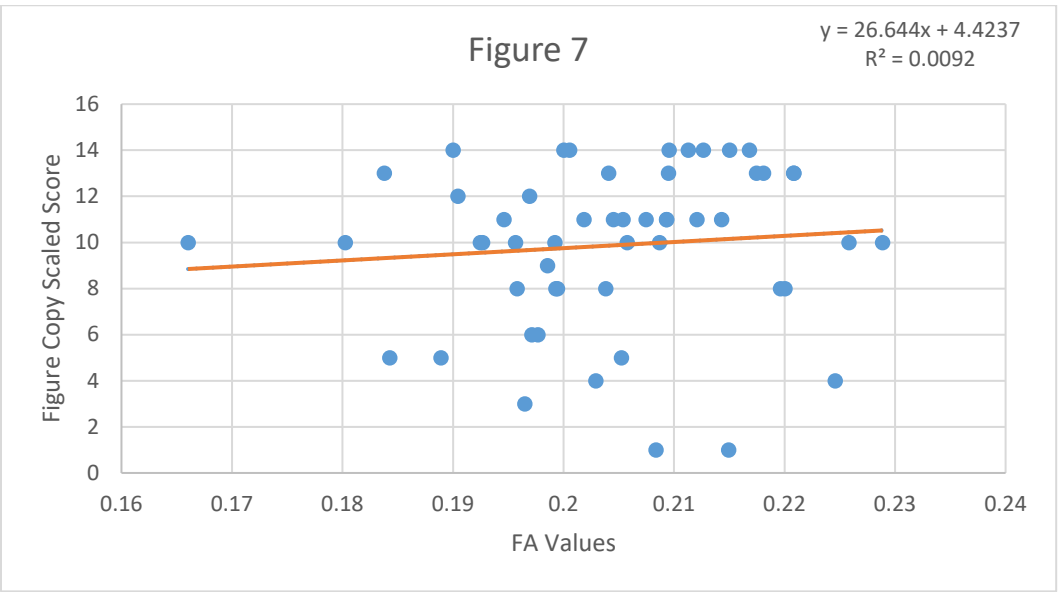


Figure 5
y = 14.704x + 7.1465
R² = 0.0038
Digit Span Forward Scaled Score
FA Values
0
2
4
6
8
10
12
14
16
18
0.16
0.17
0.18
0.19
0.2
0.21
0.22
0.23
0.24



Within the RBANS, FA values were positively correlated with Figure Copy ($R^2 = 0.01$, $p \geq 0.05$) and Figure Recall ($R^2 = 0.06$, $p \geq 0.05$), and also with Story Memory ($R^2 = 0.16$, $p \geq 0.05$) and Story Recall ($R^2 = 0.11$, $p \geq 0.05$) (See Figures 7-10).



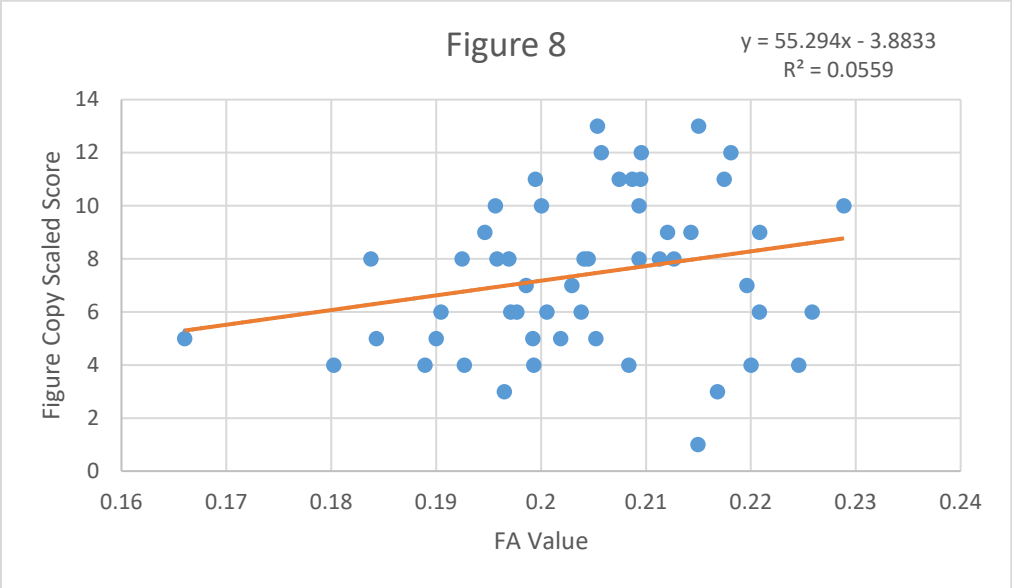


Figure 8
y = 55.294x - 3.8833
R² = 0.0559
Figure Copy Scaled Score
FA Value
0
2
4
6
8
10
12
14
0.16
0.17
0.18
0.19
0.2
0.21
0.22
0.23
0.24

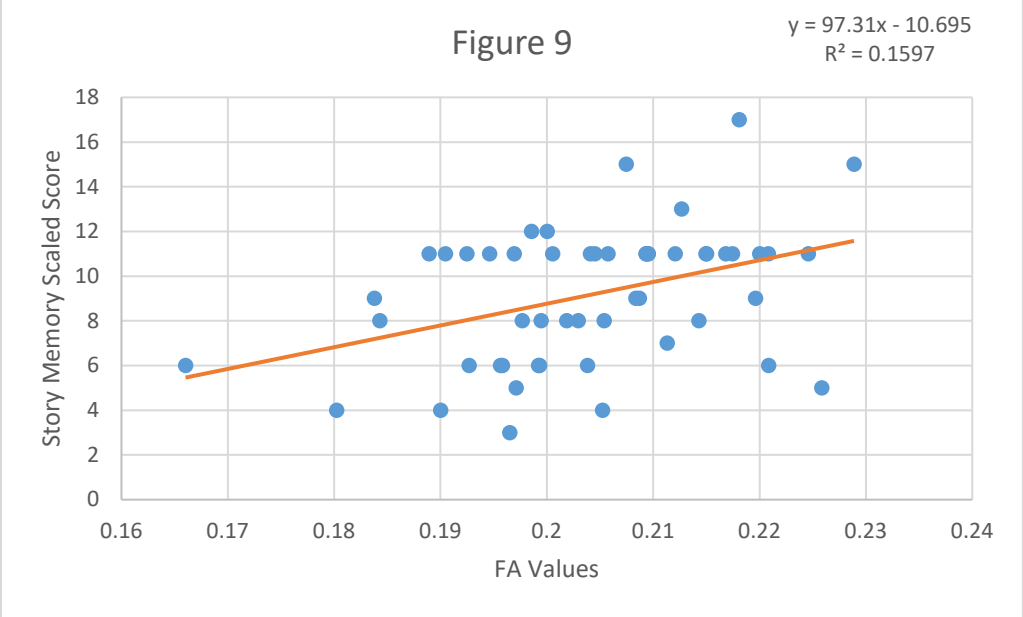
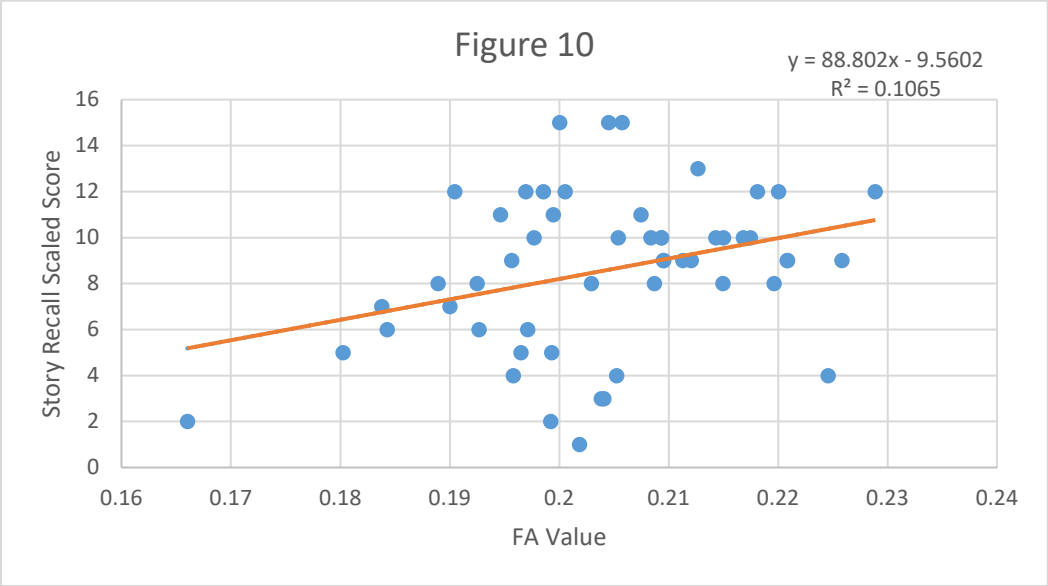
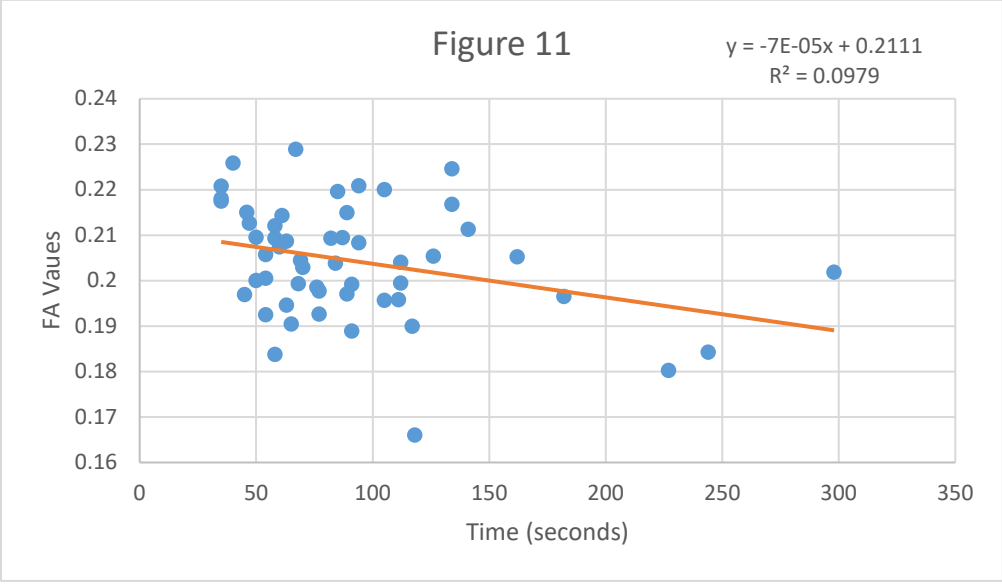
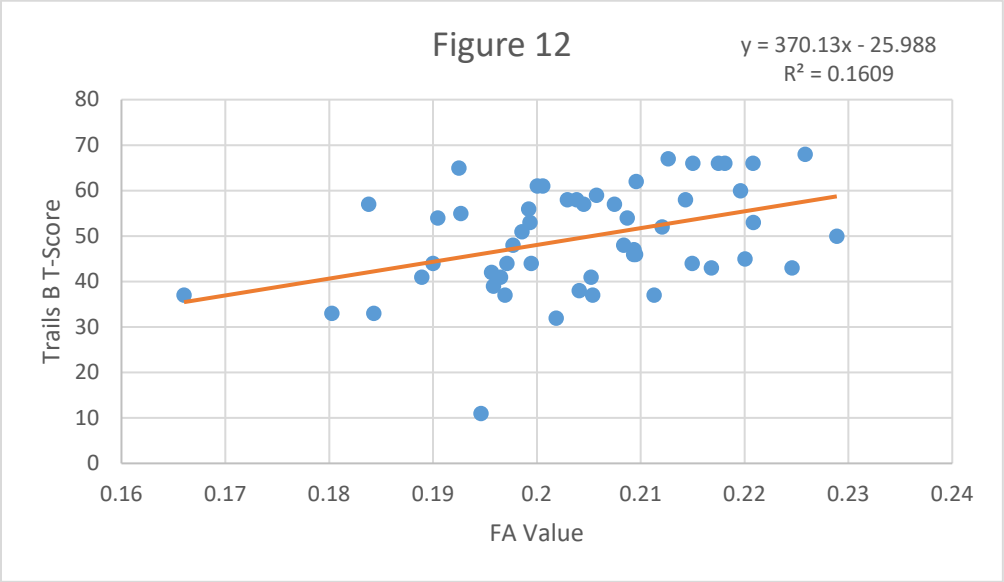


Figure 9
y = 97.31x - 10.695
R² = 0.1597
Story Memory Scaled Score
FA Values
0
2
4
6
8
10
12
14
16
18
0.16
0.17
0.18
0.19
0.2
0.21
0.22
0.23
0.24

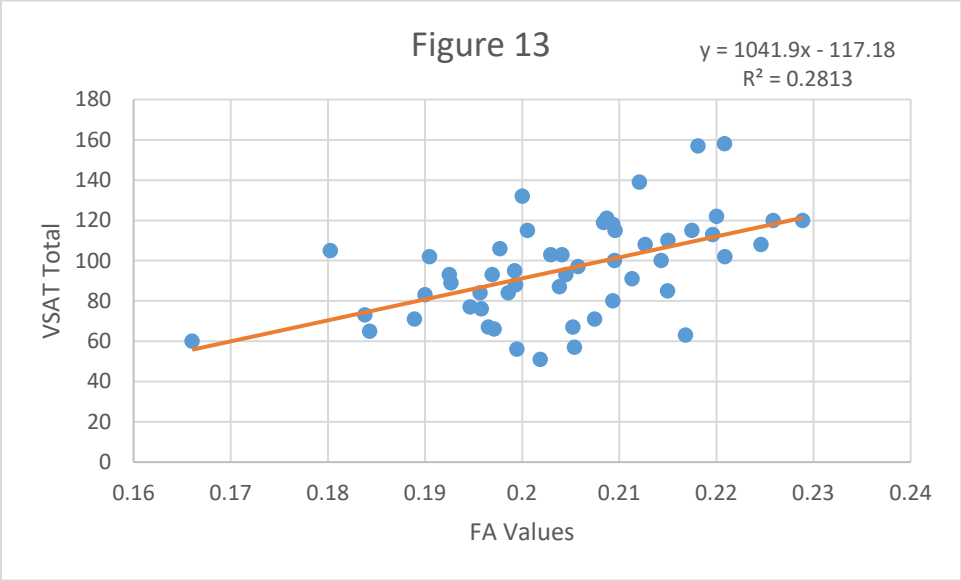


For Trails B, FA values were negatively correlated with time to complete Trails B ($R^2 = 0.10$, $p \geq 0.05$) but positively correlated with Trails B T-score ($R^2 = 0.16$, $p \geq 0.05$) (See Figures 11 and 12).





For the VSAT, FA values were positively correlated with VSAT total score ($R^2 = 0.28$, $p \geq 0.05$) (See Figure 13).



Discussion

The results of this study demonstrated that FA values are lower among those with TBI than the control group. This was an expected result, as lower FA values reflect damaged WM and have been reported in other TBI samples. However, when sex was accounted for, no significant difference was found regarding the mean FA values between male and female healthy control or male and female TBI patients. However, there was a trend towards significance regarding lower FA values for males than females with TBI. A larger sample size would be useful to determine if this trend continued. Additionally, no difference was found regarding the average FA standard deviation between TBI males and females and HC males and females. Given these results, this study generated no results to support the hypothesis than males and females have differential FA values pre- and post-TBI.

The results also demonstrated the higher FA values generally resulted in better neurocognitive performance. However, not every neuropsychological test was impacted by FA to the same extent. For example, while Digit Span and Figure Copy had statistically significant positive relationships between FA value and performance, the effect sizes were very small. Both of these tests are measures of memory, potentially indicating FA is not a powerful tool to predict this aspect of cognitive performance. This result contradicts the findings in Mesulam (1998), who found that damage to WM leads to diminished memory ability. Perhaps FA was unable to predict memory performance but another measure of WM integrity would reflect the findings of in Mesualm's study. Tests such as Trails B, Coding, and Symbol search all had R^2 values that reflected a non-trivial influence of FA values on test performance. Each of these tests is a measure of processing speed, indicating that FA may be a useful tool to predict this aspect of

cognition. The largest R^2 was found in the VSAT, indicating that this test was influenced most by FA. The VSAT is a measure of sustained attention, potentially indicating that FA may be most useful as a measure of an individual's ability to concentrate.

Limitations exist within this study. To begin, the small sample size could have prevented statistical significance to have been found. The small sample size was especially impactful when separating the TBI and HC groups by sex. For example, analysis of the female TBI group only had 8 subjects. A future experiment should recreate this study with a larger sample size. Also, the aging population involved in this study prevents generalization to the younger population. It could be that FA values do not impact younger individuals' cognitive function in the same way and to the same extent as this older population has demonstrated. A future study with a wider age range of participants should be conducted. Lastly, only using mean FA could have prevented a nuanced appreciation of WM injury and cognitive deficit. In the future, other measures of anisotropy, such as mean diffusivity or radial diffusivity, should be included to determine if they are better suited to determine relationships between WM integrity and cognition.

Conclusion

In summary, mean FA was found to be significantly different between the HC and TBI groups. No significant difference in mean FA was found when separating either group by sex. FA was found to consistently have significant relationships with measures of cognitive performance. Measured of processing speed and sustained attention were most influenced by FA values, potentially indicating that FA could be used as a powerful tool to help determine an

individual's cognitive ability. In the future, the effect the FA has on other aspects of function should be investigated, such as the influence of FA on motor ability.

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John Wesley Meyer

Academic Vitae

EDUCATIONAL HISTORY

The Pennsylvania State University, University Park Campus, State College, PA — Spring 2023
Schreyer Honors College
Bachelor of Science in Psychology with a Neuroscience Option
Minor in Philosophy
Honors in Psychology

HONORS AND AWARDS

Schreyer Honors Scholar — Fall 2019 - Present
Dean's List, Pennsylvania State University — Fall 2019 - Present

RESEARCH EXPERIENCE

The Pennsylvania State University Clinical Neuropsychology Laboratory
Research Assistant — Fall 2020 - Present
Principle Investigator: Frank G. Hillary, Ph.D.

- Currently helping assigned graduate student mentor to develop a paper on diffuse tensor imaging, fixel based analysis, and participant enfranchisement
- Currently working on an independent honors thesis investigating the influence of specific white matter pathways in relation to motor output
- Receiving training in diffusion tensor imaging and continuing to grow my knowledge in this area
- Receiving training in fixel based analysis and continuing to grow my knowledge in this area
- Entered neuropsychological data into REDCap for a PA Health project
- Lead in the creation of the BRITNE neuropsychological database
- Organized imaging data files in a database
- Coded a variety of relevant scientific articles
- Collaborated with fellow research assistants on various tasks
- Worked with an assigned graduate student
- Attended biweekly laboratory meetings
- Attended weekly meetings with team of graduate students
- Lead the undergraduate quality control of entered data

POSTER PRESENTATIONS

Meyer, J., Carter, E., (April, 2021). *Serotonin's Role in the Development of Spirituality.* Pennsylvania State University Psi Chi Annual Conference, State College, PA.

CONFERENCES ATTENDED

Diversity in Healthcare: Sourcing Solutions for Better Outcomes Tomorrow, Pennsylvania State University, April 3, 2022

RELEVANT EXPERIENCES

Teacher's Assistant for Dr. Emma Rose's PSYCH 260 course	Spring 2022
Teacher's Assistant for Dr. Michelle Yarwood's PSYCH 435 course	Spring 2023
In-Home Elderly Caregiver, Home Instead	Spring 2022 – Spring 2023

LEADERSHIP

President, Christian Student Fellowship, Pennsylvania State University	Fall 2021 – Winter 2022
Vice President, Christian Student Fellowship, Pennsylvania State University	Spring 2021 - Fall 2021
Treasurer, PSU Grappling Club, Pennsylvania State University	Spring 2020

CAMPUS ACTIVITIES

Christian Student Fellowship, Pennsylvania State University	Fall 2020 - Present
Penn State Grappling Club, Pennsylvania State University	Fall 2019 – Spring 2020
PSU Weightlifting and Bodybuilding Club, Pennsylvania State University	Fall 2019 – Spring 2020

PROFESSIONAL DEVELOPMENT

CITI Social and Behavioral Human Subjects Research, Pennsylvania State University;
CITI IRB-01 Mandatory Training, Pennsylvania State University;
CITI Social and Behavioral Research Best Practices for Clinical Research, Pennsylvania State University;
CITI OSHA Bloodborne Pathogens, Pennsylvania State University;
CITI COVID-19 Public Training Series, Pennsylvania State University;
EHS Initial Laboratory and Research Safety Training, Pennsylvania State University
UF HIPPA Training, Florida State University