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DEPARTMENT OF KINESIOLOGY

Effect of Sex and History of Concussion on Spatial Memory Scores: A Retrospective Study

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ABSTRACT

Concussions can occur due to a variety of injury mechanisms. Since the brain can move in many different directions during an impact, multiple areas of the brain may be injured. When combined, these components result in a complicated injury with numerous resulting symptoms. These symptoms can be debilitating by negatively affecting many aspects of cognition and daily living. In this study, participants were cognitively tested through a virtual reality testing modality. The system evaluates participants' spatial memory, reaction time, and balance. For the scope of this study, only spatial memory was examined. The spatial memory scores of four different subject groups were assessed and compared. Subject groups included females with a history of concussion, females without a history of concussion, males with a history of concussion, and males without a history of concussion. Analysis revealed that between the two groups without a history of concussion, males had higher spatial memory scores than females. This result was not significant but is important to include with analysis of data and examine for potential clinical relevance. Between the two groups that had a history of concussion, however, females had higher spatial memory scores than males showing presence of concussion history did not negatively impact female spatial memory scores more than their male counterparts, contrary to what was anticipated. Although this difference was not significant, the findings could be due to a compensatory mechanism after injury, time since concussion, or sample size. When an individual is injured, this mechanism can occur when someone uses a different skill, that they are stronger in, to help advance their weaker abilities. The main research question being explored in this paper is: Does the sex and/or history of concussion affect spatial memory scores?

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INTRODUCTION

Each year throughout the United States, there are over 2 million diagnosed concussions (Chong, C. & Schwedt, T., 2018). There are a variety of mechanisms in which a concussion can occur, and the resulting symptoms may vary. Symptoms commonly associated with an impact to the brain include cognitive impairments, headaches, balance issues, memory deficiencies, and impaired reaction time (Giza, C. et. al., 2018). This research project aims to specifically analyze the spatial memory of individuals with different sex and previous history of concussion given inconsistent findings from the literature. Prior research studies investigate effects of concussions on individuals, but do not primarily focus on differences between males and females. When studies separate their subject groups into male and female, results are often inconclusive. These points are behind the creation of this research project.

Since the brain is made of primarily fat and soft tissues sitting in the hard skull, when a head injury is experienced, the brain can be affected in multiple ways (Johns Hopkins Medicine, 2021). Depending on how hard the impact is and to what part of the brain the impact is experienced, the resulting symptoms are different for every concussion. Once injured, there are a series of events that occur which cause a cascade of secondary, negative events to take place. After most impacts to the brain, there is disruption between neurotransmitters, which causes a mismatch with how much energy needs to be supplied to help regulate cognitive processes, production of ATP, and maintenance of homeostasis (Mergenthaler, P., et al., 2013). When the brain uses more glucose than it is taking in, there is an energy crisis and the normal brain processes cannot continue to function regularly. In addition, more calcium is needed to upkeep the extra energy being used by the brain. (Giza, C. et. al., 2018). The brain has to complete excess work to return back to its prior state of functioning

Memory issues, specifically spatial memory, are caused from damage to white-matter material in the brain. White matter is made up of mostly myelinated axons from the nerves in the brain and has been found to be easily damaged when the brain suffers an injury (Giza, C. et. al., 2018).. The impaired white matter can cause deficits with overall cognition and memory decline (Giza, C. et. al., 2018).

Following head injury, males and females can present with different symptoms based on biology. From completed research studies, females are commonly found to experience more concussions than males (Mollayeva, T. et. al., 2018). Some current literature states that this phenomenon is due to an abundance of reasons. In one study, females were reported to have unstable neck muscles, which might make them more vulnerable to experience a more severe head injury (Mollayeva, T. et. al., 2018). Also, possibly due to the differing hormones, females have been found to report a higher pain severity response associated with injury versus males (Mollayeva, T. et. al., 2018).

Along with contrasting information with differing physiology in male and female brains, there are also sex disparities in spatial memory. In a study of healthy participants, males and females were both given the same series of tests to assess their overall memory functioning. Males were found to perform better on spatial reasoning tasks, while females had higher scores with spatial memory tests (Rahman, Q. et. al., 2005). Females completed the tests with making less errors as compared to the males, but the males were able to better imagine the space orientation of objects. Even though the females performed better on spatial memory tasks, there were no significant results from the study.

Despite this evidence, there is still inconclusive research on how males and females brains respond to a previous head impact regarding spatial memory performance.

The main objective of this research project is to explore how an individual's spatial memory is affected by their sex and history or non-history of concussion. This topic is significant in research, because there is an absence of conclusive research studies within the literature regarding sex differences in concussions. Since males and females can potentially respond to injury differently, it is important to examine both males and females and focus on comparing the results. The research design of this project will be a cross-sectional retrospective design with four groups: females with no history of concussion, males with no history of concussion, females with a history of concussion, and males with a history of concussion. Participants' spatial memory scores will be retrieved from the virtual reality database, evaluated, and compared with the scores of other groups. Based on previous literature, it was hypothesized that individuals with history of concussion would have lower scores than their peers without a history of concussion. Further, it was hypothesized that females with a history of concussion will have the lowest spatial memory scores as compared to the other subject groups, because they are more effected by concussive injury (Hannah, T. et. al., 2021).

METHODS

PARTICIPANTS

The research subjects were individuals who have data stored onto a virtual reality testing system, from previously IRB approved studies. The inclusion criteria included both males and females who either have a stated history of concussion, or no history of concussion. The inclusion age range for participants is from 18-23 years old. The exclusion criteria included individuals who have attention deficit hyperactivity disorder (ADHD) and/or a learning disability (LD). Exclusion criteria was determined based on current literature stating that individuals with ADHD can respond differently to concussion and present diverse symptoms. ADHD can cause differing effects to someone who has suffered a concussion, and due to inconsistent data on this subject group they will be completely excluded (Lambert, et al., 2021). In addition to individuals with ADHD being excluded, subjects taking any antidepressants or anti-anxiety medication were also not included in the study. These groups of medications have been found to drastically change the brain chemistry and increase the reactive oxygen species in the brain (Kim & Priefer, 2020). In addition to these criteria, the included participants were asymptomatic and were fully cleared at the time of testing. It was important to make sure that no subjects had ongoing concussion symptoms to indicate there was no presence of post-concussive syndrome. Due to the conflicting literature and altering effects of the ADHD and antidepressant/anti-anxiety-taking groups, it was decided best to remove these groups to lessen the errors of the study.

A total of 89 subjects were included in the study separated into four groups: Men with No History of Concussion (N=25), Women with No History of Concussion (N=24), Men with a History of Concussion (N=21), and Women with a History of Concussion (N=18).

STUDY DESIGN

The data collected is from pre-existing data stored in the HeadRehab virtual reality testing system. The virtual reality testing system evaluates three major components: balance, spatial memory, and reaction time. The participants that were tested would have filled out a consent, demographic, and injury history form to assess if they matched the study's proposed inclusion and exclusion criteria. If the participants were able to take part in the study, they would be tested with the virtual reality system's battery of tests.

The purpose of these tests are to evaluate an individuals' reaction time, spatial memory, and balance. The sensitivity and specificity for each section of tests all had above a 95% sensitivity for and ranging from 89% to 96% specificity (Teel, E. et. al., 2016). The sensitivity of a test shows how well a test can determine if an individual is positive with a disease or condition based on the test results, while the specificity of a test is able to conclude if an individual is negative with a disease based on the test results (New York State Department of Health, 1999).

Even though this testing system measures balance, spatial memory, and reaction time, only the spatial memory data were used for this research project. The spatial memory tests directs the participants through a randomized series of hallways, and then shows them the reverse route. The individual must remember the initial path and the reverse path through the maze, then use a remote to move themselves throughout the maze. The spatial memory score is given on a scale from 0 to 10. A higher score means that the subject was able to properly complete the maze route, and a lower score means that the subject had difficulties while completing the maze. Pre-existing data was retrieved based on individuals that meet the inclusion and exclusion criteria.

Participants were also asked to complete a subject information form that included demographic information like age, height, weight, port played, position, a self-reported history of psychiatric diagnoses, and history of concussion.

This data was collected from four studies approved by the Pennsylvania State University Institutional Review Board: #00020590, #00012528, #00010915, and #00006820.

STATISCAL ANALYSIS

Eighty-nine (N=89) participants were recruited based on sample power and effect size calculations. Sample size was calculated using an effect size of 0.95, and alpha of 0.05, a power of 0.8 (Becker, 2000). Subjects were parsed into four groups based on sex and concussion history. These groups included male non-concussed, male concussed, female non-concussed, and female concussed. An independent sample t-test was used to identify differences in mean spatial memory scores between sexes and history of concussion separately. A one-way ANOVA test was utilized to examine differences in spatial memory scores between all four groups. Simple linear regression with ANOVA was used to identify associations between number of concussion and spatial memory score. A linear regression model with an interaction variable was used to evaluate the interaction of history of concussion on the effect of sex on spatial memory.

RESULTS

Virtual reality spatial memory scores and status of history of concussion were obtained from prior research studies with a total of 89 participants. These prior studies measured various participants' ability to complete a virtual maze and they received a spatial memory score based on their performance. In a history and demographics form, the participants indicated age, handedness, sex, ADHD/LD and psychiatric diagnosis, and if they had a previous concussion injury. Demographic information corresponding to the current study can be found in Table 1.

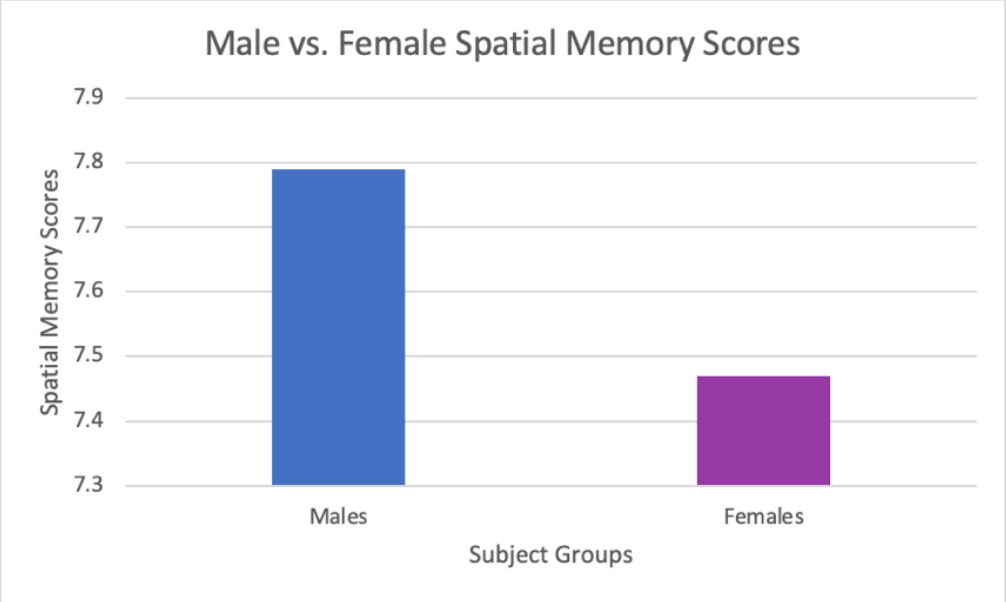
Table 1: Demographic Data of Study Participants (N=89).

Age, *mean ± standard deviation*	21.43 ± 2.43
Handedness, *N= (%)*	Handedness, *N= (%)*
Right	79
Left	10
N/A	0
Sex, *N= (%)*	Position, *N= (%)*
Male	46
Female	43
Previous Concussion History, *N= (%)*	Previous Concussion History, *N= (%)*
0	50
1	27
2	10
3	2
ADHD Diagnosis, N= (%)	ADHD Diagnosis, *N= (%)*
Yes	0
No	89
N/A	0
Psychiatric Diagnoses, *N= (%)*	Psychiatric Diagnoses, *N= (%)*
Yes	9
No	80
Family History of Psychiatric Diagnoses, *N= (%)*	Family History of Psychiatric Diagnoses, *N= (%)*
Yes	15
No	74
Months Since Concussion, *N= (%)*	Months Since Concussion, *N= (%)*
Male	60.73
Female	68.83

Scores were compared between four main groups: males with history of concussion (n=21), males without history of concussion (n=25), females with history of concussion (n=18), and females without history of concussion (n=25). Specifically, there were 46 male participants and 43 female participants. Additional demographic information corresponding to the current study can be found in Table 1.

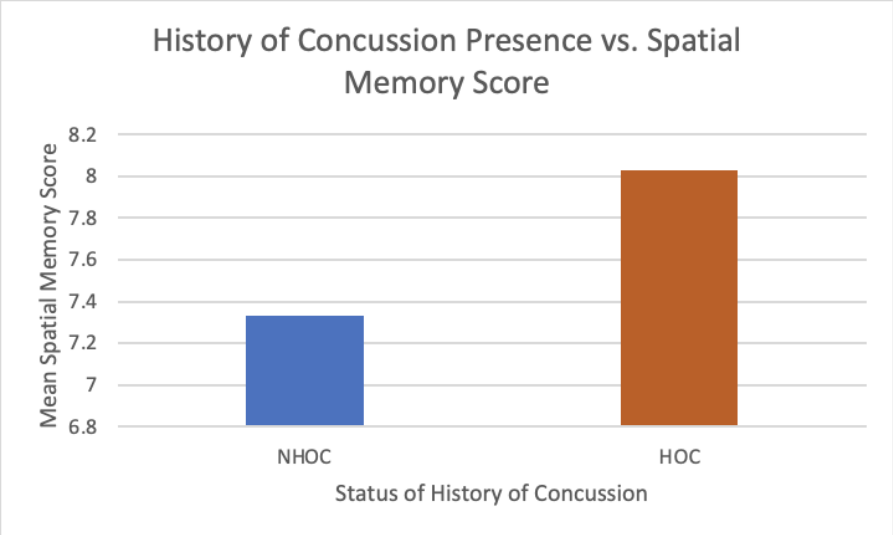
Figure 1 represents the relationship between the sex of the participants and their reported spatial memory scores. Means of male and female spatial memory scores we compared using an independent samples t-test. Males reported better spatial memory scores, but means were not significantly different between sexes (F=0.30, p=0.862). of spatial memory for each subject group were taken and compared. The female group with a history of concussion displayed the highest average spatial memory scores (8.7) and the female group with no history of concussion showed the lowest average spatial memory scores (7.0).

Figure 1: Male vs. Female Spatial Memory Scores.



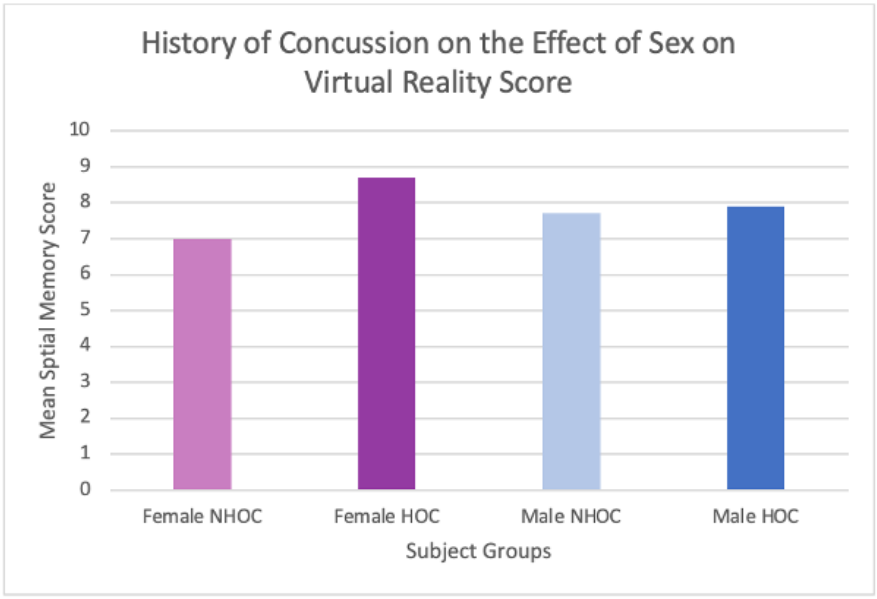
An independent samples t-test was also utilized to compare mean spatial memory scores between participants with and without a history of concussion. Means were not significantly different between these sub-samples (F=8.536, p=0.78).

Figure 2: History of Concussion vs. No History of Concussion Spatial Memory Scores.



One-way ANOVA was utilized to examine differences in spatial memory between the four major participant groups. There was no difference between groups in spatial memory (F=1.609, p=0.193). Spatial memory scores for each group are detailed in Figure 3.

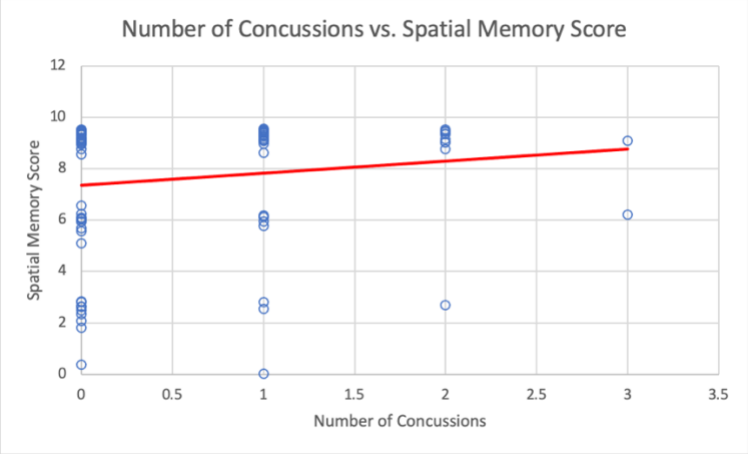
Figure 3: History of Concussion on the Effect of Sex on Virtual Reality Score.



*HOC= History of Concussion
*NHOC= No History of Concussion

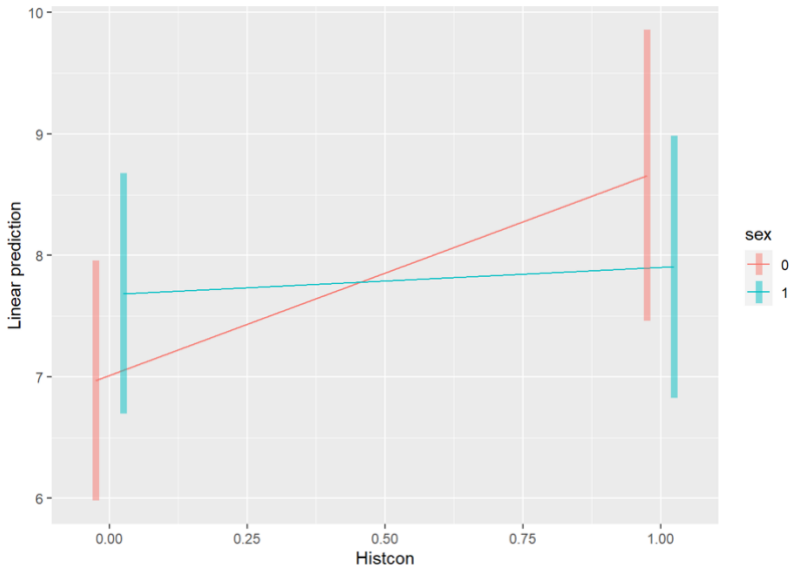
A simple linear regression, using ANOVA showed no significant association between number of concussions and spatial memory score (F=2.144, p=0.147). However, there was a noticeable increase in spatial memory as number of concussions increased, which was counterintuitive to the study hypothesis.

Figure 4: Number of Concussions vs. Spatial Memory Score.



A linear regression model with an interaction variable was used to evaluate the interaction of history of concussion on the effect of sex on spatial memory. Figure 5 shows that as in healthy individuals males score higher than females in spatial memory, but that in those with a history of concussion, females score higher than males. Although this relation is not statistically insignificant (p=0.1748), the effect of concussion on spatial memory, although in the opposite direction as predicted, seems to exist more in females than males.

Figure 5: Interaction of History of Concussion on the Effect of Sex on Spatial Memory.



In the included figure, history of concussion is presented as 0 and 1. A bar on the 0 represents no history of concussion and a bar on the 1 represents a history of concussion. The pink line, also shown as a sex of 0, represents the female participants. The blue line, shown as a sex of 1, represents the male participants. The x-axis exhibits the presence of history of concussion and the y-axis shows average spatial memory score.

From the five presented figures, there was no found significance in any of the calculated data. The presence of concussion history did not significantly affect spatial memory scores of the groups. In addition to concussion history, the number of concussions from each group with history of prior concussions did not have a significant effect on spatial memory scores. The individual sex of the participants in the research study did not have any effect on the recorded spatial memory scores. Looking at the variables of sex, incidence of concussion history, and spatial memory scores, females without a history of concussion had lower spatial memory scores as compared to males without a history of concussion. With the presence of concussion history, females had a higher spatial memory score as compared to males.

DISCUSSION

The main goal of the completed research study was to investigate differences in spatial memory scores between males and females with and without a history of concussion. The data used in this research project was obtained from prior research studies and the results were analyzed. The main finding in the statistical analysis was that concussion history did not negatively impact female spatial memory scores as much as male spatial memory scores. In addition to this finding, without a history of concussion, female spatial memory scores were lower than male scores. These statistical findings help to disprove the initial hypothesis presented, that females with a history of concussion would have the lowest spatial memory scores. However, females with a history of concussion have the highest spatial memory scores out of four subject groups.

Additional results obtained that were not significant, but potentially important to include clinically. As number of concussions in the participants increased, so did the average spatial memory scores. This outcome also works to disprove the main hypothesis by indicating the presence of a prior concussion increases spatial memory scores.

The entirety of results from the study completed were not expected. Based on prior literature, females were expected to have lower spatial memory scores, signifying a decrease in performance. In a study completed by Rahman et. al., females were found to have better overall spatial memory scores, but worse functioning regarding orientation spatial memory tasks. The results from this study were not conclusive and could not provide insight into how males and females differ in total spatial memory functioning (Rahman, Q. et. al., 2005). There were unexpected results in this study which can be explained further. The females with a history of concussion could have used a compensatory mechanism to offset any present weaknesses with their spatial memory abilities. A compensatory mechanism uses cognitive processing to counter

any present or perceived flaws in performance (American Psychological Association, 2023). While an individual is known to have worsening state of function regarding a specific task, like in the case of an individual knowing they might perform worse after a concussion, they begin to overcompensate and put additional effort into the task. Regardless, the female group with a history of concussion was hypothesized to perform the worst on the spatial memory tasks, but they had the highest overall spatial memory score.

An additional reasoning behind why the certain results were obtained can be attributed to the resilience of the subjects. Since the average age of subjects was 21, their ability to fully recover from the concussion may not be negatively affected by age. Due to their potential high resilience, the subjects would be able to perform to their full potential in cognitive and spatial memory testing, regardless of history of concussion. If they were of a different age group, their history of concussion might cause more of an effect to their spatial memory abilities. In a research study completed by Nelson, L. et al. the recovery time period after a concussion was compared between high school and collegiate athletes. The high school participants took 1-2 days longer to recover, according to a score produced from the Standardized Assessment of Concussion, as compared to the collegiate athletes (Nelson, L., et al., 2016). While examining the results of this study, it begins to bring awareness to the notion that age can play a role into how an individual can recover from a concussion.

There are certain limitations present in the completed study that could cause discrepancies with the data. One restriction with this study is the sample size present for each subject group. There was a total of 89 subjects with 25 subjects in the men with no history of concussion, 24 women with no history of concussion, 21 men with a history of concussion, and 18 women with a history of concussion. Increasing these group sizes may help to mitigate issues

of statistical power and the influence of participant overcompensation. Another limitation to this study was how many months it has been since the reported concussion in the history of concussion subject group. With the male group of history of concussion, the average number of months since reported concussion was 60.73 months. The female group with history of concussion, the average months since reported concussion was 68.83 months, counted from 11/1/22. There was no restriction of how long it has been since the reported concussion, which may indicate individuals with a concussion history greater than 5 years show no residual effects in spatial memory. A final limitation of this study was regarding data collection. While there are measures taken to avoid mistakes made during the research, there are some possible errors that can occur, and could have occurred, during data collection. As stated previously, pre-existing data was used for data collection and analysis. One potential issue with the data collected prior, is that the remote controller used by the subjects to take them through the maze could have been faulty. There have been occasional cases where the remote malfunctions and makes the subjects watch the maze route again, lowering their spatial memory score. Another problem that could have presented itself was a lack of effort by the participants completing the maze. Some of the data collected is from athletes and they were asked to complete the spatial memory testing various times throughout their season and training program, which may have affected their effort or attention.

Further directions and advancements of this research project can be directed towards focusing research topics on differences in the various aspects of a concussion in males and females. This study helps to show how males and females can respond differently and provide contrasting test results than expected. The driving force of this research study is due to the inconsistent literature surrounding sex differences in concussion. There are various research

articles that do not point to conclusive answers as to how males and females distinctly respond to a concussion. While concussion treatments are still be explored and validated, the sex of the patient being treated needs to be taken into consideration, seeing how they can be affected differently. Further avenues for research on this topic of sex differences in concussion outcome are evaluating balance abilities, reaction time, and sleep differences. The virtual reality testing system also tests the participant's balance and reaction time. As an additional component of this research project, the trends of balance and reaction time can be evaluated and compared to the results of this study.

The participants in this research study did not have any concussion symptoms and were fully cleared at the time of the virtual reality testing. The group with history of concussion was evaluated primarily on the presence of a prior concussion, not the symptomology after their concussion. It was unexpected to have increases in spatial memory score values when all subjects were not experiencing any concussion or neurodegenerative symptoms. While unpredicted results occurred from this research, the outcomes can be helpful in learning more about different variables associated with concussion recovery. Concussion symptoms and downstream effects take varying time to dimmish for each individual person and injury. Even though an individual might seem fully cleared, it is important to fully assess the affected person and find any potential deficits they might still have. Additional research on this topic could assist in providing more information on sex differences in individuals who have had a concussion with a particular focus on spatial memory capacity and performance.

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ACADEMIC VITA

Anna Farantzos

Education

The Pennsylvania State University — Expected 05/2023
Major: Bachelor of Science in Kinesiology
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Research Experience

Concussion Laboratory Research Assistant — 09/2020-Present
The Pennsylvania State University — *University Park, PA*

- Learned laboratory technologies such as virtual reality and balance training modules
- Assisted in data input from ongoing research projects
- Worked toward completing Schreyer Honors Thesis

Concussion Laboratory Administrative Assistant — 09/2022-12/2022
The Pennsylvania State University — *University Park, PA*

- Organized data input for laboratory research projects
- Conducted subject testing on virtual reality and balance testing modalities

Teaching Experience

BIOL 163 Learning Assistant — 08/2020-05/2021
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Leadership

Phi Eta Sigma Secretary — 01/2020-04/2021
The Pennsylvania State University — *University Park, PA*

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- Responsible for reporting club information to members

Phi Eta Sigma Vice President — 04/2021-Present
The Pennsylvania State University — *University Park, PA*

- Created the agenda for monthly club meetings
- Assisted president in keeping track of distinguished status members

Phi Eta Sigma President — 04/2022-Present
The Pennsylvania State University — *University Park, PA*

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- Worked cohesively with other executive board members
- Resolved questions or concerns with aspects of organization

Awards:

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Activities

Schreyer Honors College 09/2020-Present
The Pennsylvania State University *University Park, PA*

- Demonstrated academic eminence through advanced coursework
- Completed Honors Thesis