NSU Florida
NOVA SOUTHEASTERN UNIVERSITY

Journal for Sports Neuroscience

Volume 2 | Issue 1 Article 4

November 2024

The Effect of Exercise Type on Working Memory

Ariana Gonzalez
Nova Southeastern University, ag3311@mynsu.nova.edu

William R. Kochen
Nova Southeastern University, wkochen@nova.edu

The Effect of Exercise Type on Working Memory

Abstract

Martial arts encompass a wide range of sports and techniques that have been practiced for self-defense and combat for thousands of years. It has expanded to include various styles such as Brazilian Jiu-Jitsu, Taekwondo, judo, and karate. It has also been practiced as a form of exercise and entertainment. Martial arts have been associated to discipline, integrity, improved stamina, and increased mental and problem-solving capabilities. Unlike other exercise methods, most martial arts require focus, skill, and technique, which have been hypothesized to improve memory. The purpose of the study was to determine if there was a significant improvement in the working memory of young adults who participated in martial arts and it was compared to people that exercised and people that were minimally active. The mean age for the participants was (M = 22), 74 males and 76 females, and there were 50 participants in each experimental group. The hypothesis was that young adults who train in martial arts would have a better working memory than those who exercise or do minimal physical activity. Working memory capability was measured by performing a digit span test, where participants were asked to memorize a growing sequence of numbers.

The average digit span from the martial arts group was 6.32 compared to 5.88 for the exercise group and 5.79 for the minimal exercise group. When analyzing these values between groups, the difference was significant $F(2, 147) = 3.05$, $p = .05$. However, there was no significant difference in the post hocs ($p = .056$). The standard deviation between the various digit span averages in the three groups was 0.28. There was a significant difference in perceived memory between groups, $F(2, 147) = 13.44$, $p < .001$. There was also a significant difference in post hocs between martial artists and those who do minimal physical activity ($p < .001$) and athletes and those who do minimal physical activity ($p = .005$). Furthermore, there was a significant difference between males and females, $F(2, 147) = 4.70$, $p = .011$. There was also a significant difference in post hocs between the ratio of males and females in the martial arts group and the athlete group ($p = .007$). There were no other significant differences when comparing other factors such as age, education, years in training, and training frequency. These results indicate that martial artists have a greater working memory than athletes and those who do minimal physical activity when comparing between groups († = .05). Furthermore, martial artists displayed a higher degree of confidence and self-esteem when asked about their perceived memory level (†† = .005) compared to athletes. When comparing perceived memory in martial artists to those who do minimal physical activity, the difference was greater ††† < .001).

While there was a significant difference between the exercise types for working memory, ($p = .05$), the post hocs were not significant, so it was unclear if one group was significantly different to any other specific group. However, the greatest significant difference in this study was that martial artists had a higher sense of perceived memory and self-confidence compared to the other two experimental groups. This could demonstrate that while martial arts increased working memory, the largest increase was the self-esteem that they gained. This could be instrumental in promoting martial arts training in young children to enhance discipline, self-control, and confidence. Further studies should also be considered to analyze whether martial arts could help retain working memory in patients with neurodegenerative disorders.

Keywords

neuroscience, martial arts, martial artists, working memory, psychology, exercise science, digitspan, Jiu-Jitsu, sports, exercise, memory, physical activity

Cover Page Footnote

We would like to thank PsyToolkit for providing the experimental survey and test.

Introduction

Martial arts have been practiced for thousands of years, originating from as early as 2000 BC in ancient Greece. Different styles of martial arts originated in many different regions and times in history. For example, taekwondo originated in Korea, and it is one of the oldest martial arts since it began over 2000 years ago. Taekwondo consists of kicks, punches, and blocks and it is a very popular sport among young children in the United States. Another style of martial arts is jiu-jitsu, which originated in Japan during the 1500s. It is called the gentle art, as it consists of grappling, application of chokes, and joint manipulations. In the early 1900s, jiu-jitsu traveled to Brazil and that is where it became what is now modern-day jiu-jitsu. Another martial art called Judo was created in Japan in 1882, and it is comprised of jiu-jitsu and sumo wrestling. The purpose of the techniques is to use throws to use the opponent's force against themselves. While these martial arts first originated for self-defense and combat, they have been shown to have many positive mental and physical effects. The majority of martial arts involve high-intensity training, such as kicking and punching for karate and grappling for jiu-jitsu. This intensity of training improves cardiovascular health and well-being (Suetake, 2018). Additionally, it has been found that martial arts serve as an efficacious mental health intervention (Moore, 2020). In another study, Judo was shown to have positive effects on working memory (Ludyga, 2022). In this study, a 12-week training program in Judo demonstrated promising improvements in both behavioral and neurocognitive levels in children with ADHD. Working memory is a type of memory that involves remembering a piece of information and using it to perform an action. For example, there are several tests that can assess working memory, such as the digit span and operation span tests. The digit span test consists of a sequence of numbers that are quickly presented and then removed. The person performing the test is expected to memorize the sequence and then select the numbers they remember in the correct order they were presented. As the test continues, the sequence of numbers becomes longer to assess their working memory capability and extent. The test is quick and easy to perform, and it is a well-designed test to accurately assess working memory.

Martial arts have been linked to increased memory and attention. In the study, “Martial arts enhances working memory and attention in school-aged children: A functional near-infrared spectroscopy study”, researchers analyzed various regions of the children’s brains by using functional near-infrared spectroscopy. After performing two tests, the d2 attention test and N-back memory test, the scientists found that martial arts increased the accuracy of the 2-back test and decreased reaction time. Furthermore, the martial artists had greater activation of the right orbitofrontal cortex and right Broca’s area. After performing this

experiment, the scientists concluded that martial arts increased neural networks that are used in cognitive control.

In the study, "The effectiveness of Tai Chi for short-term cognitive function improvement in the early stages of dementia in the elderly: a systematic literature review", the goal was to determine if Tai Chi training during early stages of dementia would improve short-term memory and cognitive function (Li, 2023). The researchers in this study analyzed nine studies, six randomized controlled trials, one non-randomized prospective study, and two non-randomized controlled trials. Each of the studies determined that Tai Chi improved visuospatial skills, learning, semantic memory, and self-perception memory.

In another study, "Effects of Olympic Combat Sports on Older Adults' Health Status: A Systematic Review", 12 studies observed older adults training in combat sports. After analyzing the data, it was determined that sports such as boxing, judo, and karate improved the physiological, psycho-emotional, and physical functions of adults over the age of 60.

While the majority of research studies were performed on adults or elderly individuals, the article, "Motor and cognitive development: the role of karate", analyzed 39 children who were divided into two experimental groups: children who regularly participated in karate training and children who were sedentary. The children were asked to do an agility test where they would measure coordination, motor, and cognitive abilities. Similar to my study, the researchers also presented a digit span test to all the participants to measure cognition. For the agility test, the researchers found that the children who participated in karate performed significantly better than those who were sedentary. They determined that these children had greater strength and coordination. They also found that the children who trained in karate performed significantly better in the Digit Span Test, Selective Attention, and London Tower Test than sedentary children. Therefore, karate had a significant impact on the physical and cognitive health of children.

Another important study was the "Effects of Physical Exercise on Working Memory and Attention-Related Neural Oscillations". The study used forty-three sedentary participants and placed them into two groups: a group that would perform aerobic exercise and a control group. The participants in the aerobic exercise group ran on a treadmill for 45-75 minutes three times a week for a total of 16 weeks. The control group only walked on a treadmill twice a week for 10-12 minutes. After the experiment was completed, the participants underwent EEG tests, and their oxygen consumption and respiratory compensation points were measured. It was then determined that the EEG tests were better in participants who performed aerobic exercise when compared to those who did not. Additionally, neuroimaging tests showed how people who did aerobic exercise had greater spatial skills but weaker fronto-parietal activation during cognitive tests, which is common in athletes. This can be determined by neural efficiency.

While there is a promising correlation between children and adults who train in martial arts and regular exercise and improvements in working memory, the results have not always been conclusive. In the study, "Acute and Chronic Exercise Effects on Human Memory: What We Know and Where to Go from Here", the researchers analyzed participants' semantic and episodic memory. It was found that there was not a significant difference between acute and chronic exercise in affecting memory (Loprinzi, 2021).

Furthermore, while exercise and martial arts have been found to have a positive impact on memory, the article, "Poor physical fitness is associated with impaired memory, executive function, and depression in institutionalized older adults: a cross-sectional study" analyzed participants who did minimal physical activity. It was found that participants who did not exercise had lower semantic fluency and even depressive symptoms.

While exercise and martial arts have been found to increase memory, their exact reason was only recently discovered and analyzed. According to the BYU Life Sciences, "How exercise affects the brain", exercise increases brain-derived neurotrophic factor (BDNF). BDNF is crucial in the growth and survival of neurons and plasticity. Higher levels of BDNF have been linked to increased learning and memory capacity. Furthermore, it has been linked to synaptogenesis which allows for the formation of memories and retention of new information. Therefore, by increasing BDNF through exercising or martial arts, a participant may be more capable of having a larger memorized digit span.

Due to the various benefits of martial arts, this study aims to determine if there is a positive correlation between martial arts training and improved working memory. This is the first study to observe the working memory of young adults who train in martial arts, those who exercise, and those who do minimal physical activity. While most research studies compared martial artists to those who do minimal physical activity, this study also compares the two groups with athletes. The goal is to determine if the benefits of martial arts are due to its high-intensity cardio training or the analytical skills that are required. We hypothesized that martial artists would have higher working memory than those who only exercise or do minimal physical activity due to the analytical and physical demands of the sport.

Methods

Participants

One hundred and fifty participants were recruited for this study between the ages of 18 to 30, and the average age was 22. The participants were grouped into three separate groups: i) people who trained in martial arts, ii) people who exercised, and

iii) people who did minimal physical activity. Participants were excluded from the study if they: i) were under the age of 18 or over the age of 30, or ii) have been training martial arts or exercising for less than one year.

In this experiment, a link and QR code leading to the survey and memory test were sent to local young adults. The QR code was also available on flyers that were posted at Nova Southeastern University. After several months of recruitment, a total of 150 participants completed the survey. There were 50 participants in each group, the group of people who trained in martial arts, those who exercised, and those who performed minimal physical activity. Participants were recruited from many different backgrounds and locations such as students from local universities, martial arts schools, and other communities. There were 43 males and 88 females. Additionally, many were from different educational backgrounds to provide variety in the data. The majority of participants had completed some college.

Four participants in the martial arts group were excluded from the study because they had been training in martial arts for less than a year. Additionally, 2 participants in the exercise group were excluded since they had been exercising for less than a year. Finally, 2 participants were removed from the study since they never completed the digit span test. Before beginning the experiment, all participants signed a written consent form. This study was approved by the Institutional Review Board (IRB) at Nova Southeastern University.

Experimental Design

In this experiment, an online survey and memory test were created on PsyToolKit, which is a website for creating and running psychological tests. The participants completed a survey that asked questions regarding age, biological sex, and education level. Participants were also asked how well they perceived their working memory. The answer choices ranged from “I immediately forget things”, “I sometimes forget things”, “I have a decent memory”, “I am usually able to remember things”, and “I always remember things”. The participants were then asked about their exercise type, such as if they performed martial arts, if they exercised, or if they did minimal physical activity. If they answered that they performed martial arts, they were asked which martial arts, how many times a week they trained, and how long they had been training. If they answered that they exercised, they were asked how many times a week they exercised and for how long they had been exercising. The survey took approximately three minutes to complete. Once they completed the questions, or if they answered that they did minimal physical activity, they were automatically taken to the digit span memory test.

The participants were first given a list of instructions before beginning the test. Additionally, the first digit span was a trial run and was only two digits long.

This first test was not scored, and its purpose was to allow the participants to understand the mechanics of the test. Once the participants completed trial one, they completed another set with two numbers. After completing a digit span set correctly twice in a row, the length of the span increased by one number. The maximum number of digits the participant could recall was nine. Once the participant had two errors, the digit span test automatically stopped and their responses and time were recorded. The participants then landed on a thank you page where they could exit and complete the study. The digit span portion of the research study took approximately four to five minutes to complete depending on the number of questions they performed correctly.

Once all of the data was collected for the 150 participants, the perceived working memory and digit span number length were plotted on bar graphs in Excel to see the average for each experimental group. For each group, the average for the digit span length was calculated. This data was then added to a bar graph to see the difference between the three groups. Two separate graphs were then created for the martial arts and exercise group to analyze their digit span to how long they have been training for and how often they trained per week. Additionally, every group's digit span was compared to their education level to determine if the difference was due to their corresponding sport or their educational level. The groups were also divided by male and female to analyze if there was a difference in digit span scores in the two groups.

The software program SPSS Statistics was used to analyze and determine the significance of the data. An ANOVA test was conducted as well as the Tukey post hoc tests. These tests compared all experimental groups and variables such as perceived memory and age.

Results

The digit span for each of the participants was determined and plotted in Excel. The average digit span in the martial arts group was 6.32. The scores varied from 5 – 9, and the standard deviation was determined to be 1.067. In the exercise group, the average digit span was 5.88. The scores varied from 3 – 9 and the standard deviation was 1.107. In the minimal physical activity group, the average digit span was 5.78. The scores varied from 3 – 9 as well and the standard deviation was 1.269. When comparing the p-value of each of the groups, the scores from the three experimental groups differed ($p = .05$), however, the post hocs did not provide a clear indication as to which experimental group was significantly different. The majority of participants trained in Brazilian Jiu-Jitsu, so it is unclear if the improvement in working memory is correlated to all martial arts training or specifically Brazilian Jiu-Jitsu. These results indicated that there was a significant interaction effect but no significant post hocs ($p = .56$). This discrepancy between the ANOVA and the

post hoc was due to the small sample size in this experiment. With a larger sample size, the difference between these two tests could be properly analyzed in order to determine if this was due to the sample size, an effect of the experiment, or a limitation in the design.

There was no significant difference between age in the experimental groups (p = .388). The average age of martial artists was 22.54, 21.78 for athletes, and 21.84 for people who do minimal physical activity. Additionally, the ANOVA indicated, $F(2, 147) = 0.95$, p = .388.

There was a statistical difference between male and female distribution between martial artists and athletes (p = .007). In the martial arts group, there was a distribution of 16 males and 9 females. The digit span score ranged from 5 – 9 in males and the same in females. The average digit span score was 6.25 in males and 6.44 in females, which was insignificant. In the exercise group, there were 17 males and 33 females, which was more unbalanced compared to the other two experimental groups. The males' digit span score varied from 4 – 8 and the females' digit span score varied from 4 – 9. The average digit span length for males was 5.71 and the average for females was 5.97. Despite the difference, it is still insignificant. In the minimal physical activity group, there were 25 males and 25 females. Males received an average of 5.8 and females received an average of 5.76 in the digit score test. The male digit span score varied from 4 – 9 and the female scores also varied from 4 – 9. Due to the even distribution, it was easier to examine the difference in digit span scores between the two groups and there was no statistical difference (p > .05). Despite the minimal difference in digit span scores between males and females, the ANOVA test determined there was a significant difference (p = .011) in the distribution of males and females between groups. Therefore, this may have impacted the results of the data.

When comparing the average digit span length to the education level for martial artists, athletes, and people who perform minimal physical activity, there was no significant difference (p > .05). The majority of participants collected for this experiment had only partially completed college, so creating a comparison between the educational level and the score did not provide a clear result. Therefore, the results from the digit span tests were based on the participant's training in martial arts rather than on education level.

In addition, there was also no significant difference when comparing average digit span length to perceived working memory in the three experimental groups. While martial artists scored a higher average digit span, their selection in the perceived memory question did not correlate to a higher digit span score.

However, there was a significant difference between groups in the participant's selection in the perceived memory question. When analyzing the post hocs, there was a significant difference between the perceived memory in martial artists and those who do minimal physical activity (p < .001). When comparing

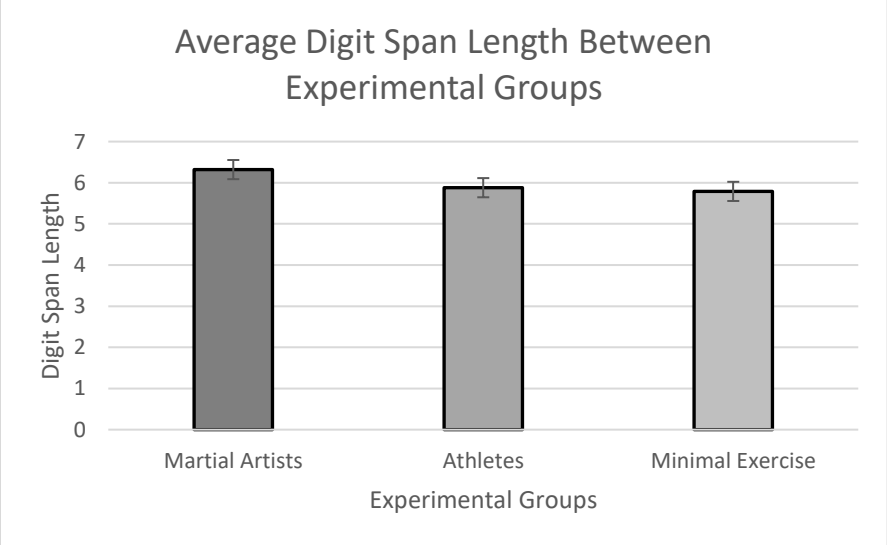
athletes to those who do minimal exercise, there was also a significant difference ($p < .005$). However, there was no significant difference between the perceived memory of martial artists and those who exercise ($p = .135$).

When comparing the average digit span length to the number of years of training in martial arts, there was no statistical difference due to an unequal distribution of participants in each of the different groups. There was a comparison of average digit span length to the number of years exercising in athletes, and the difference was negligible ($p > .05$). When analyzing the averages, there is no statistical difference between the groups.

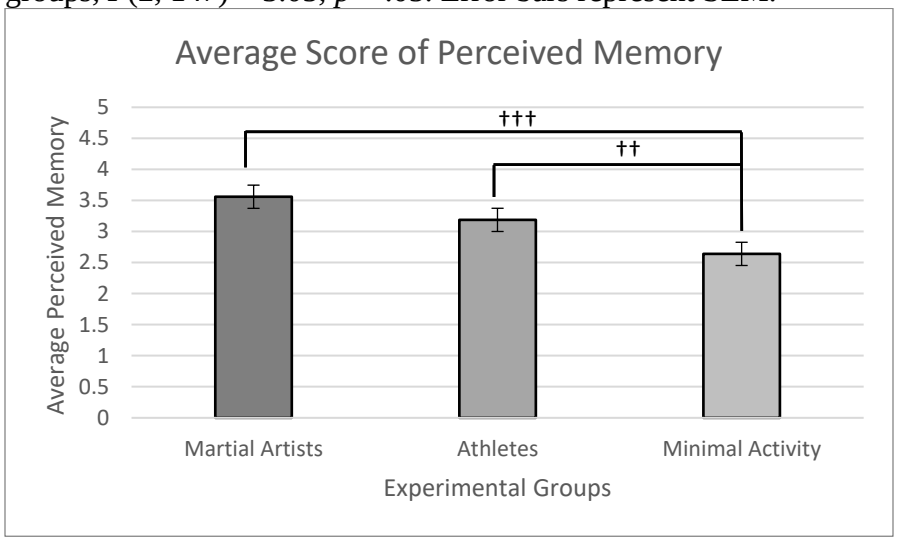
When comparing the years of training between the experimental groups, there was only a significant difference in the minimal physical group ($p < .001$). However, this was expected since participants in the minimal physical activity group reported no years of training in any physical activity. The difference between martial artists and athletes was negligible ($p = .946$) since both groups had been training for several years.

There was no significant difference when comparing the average digit span to the frequency of training for martial artists and athletes ($p > .05$). The majority of participants in these two groups trained 3 times a week.

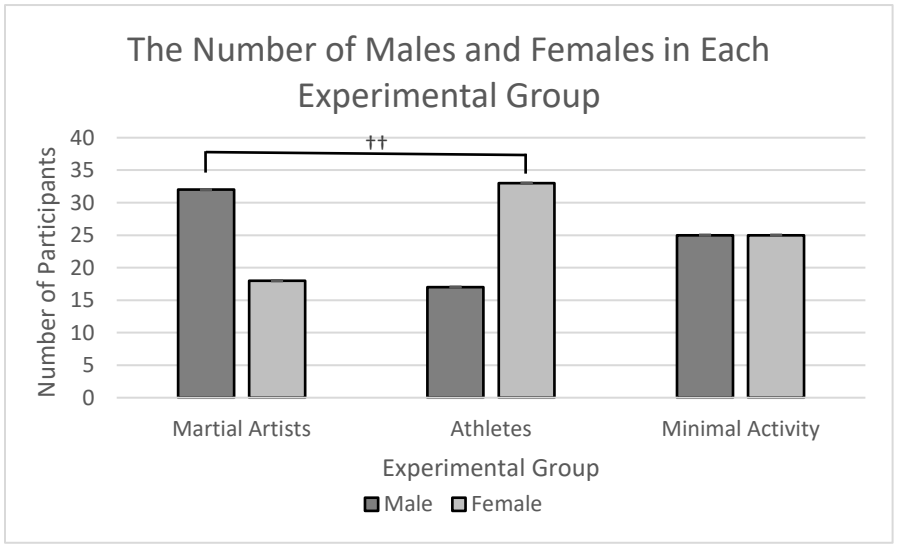
The responses in training frequency were compared between groups and it was significant ($p < .001$). This was also expected since participants in the minimal physical activity group indicated that they did not participate in physical activity. The post hocs comparing martial artists and those who exercise indicated that there was no significant difference ($p = .84$).



Graph 1. The Average Digit Span Length Between Experimental Groups. There was a significant difference between digit span length in the different experimental groups, $F(2, 147) = 3.05$, $p = .05$. Error bars represent SEM.



Graph 2. The Average Score of Perceived Memory Between Experimental Groups. There was a significant difference between groups, $F(2, 147) = 13.44$, $p < .001$. There was also a significant difference in post hocs between martial artists and those who do minimal physical activity ($p < .001$), and athletes and those who do minimal physical activity ($p = .005$). Note: †† $p < .01$, ††† $p < .001$. Error bars represent SEM.



Graph 3. Average Digit Span Length in Males and Females Between Experimental Groups. There was a significant difference between experimental groups, $F(2, 147)$

= 4.70, p = .011. There was also a significant difference in post hocs between the ratio of males and females in the martial arts group and the athlete group (p = .007). Note: †† p < .01. Error bars represent SEM.

Variable	Experimental Group	P Value	F Value	df	Standard Error
Digit Span	Martial Artists & Athletes	0.145	3.052	2	0.233
	Athletes & Minimal Activity	0.903			
	Minimal Activity & Martial Artists	0.056			
Age	Martial Artists & Athletes	0.430	0.954	2	0.612
	Athletes & Minimal Activity	0.995			
	Minimal Activity & Martial Artists	0.489			
Biological Sex	Martial Artists & Athletes	0.007	4.700	2	0.098
	Athletes & Minimal Activity	0.235			
	Minimal Activity & Martial Artists	0.328			
Education	Martial Artists & Athletes	0.937	0.061	2	0.175
	Athletes & Minimal Activity	0.993			
	Minimal Activity & Martial Artists	0.972			
Perceived Memory	Martial Artists & Athletes	0.135	13.438	2	0.187
	Athletes & Minimal Activity	0.005			
	Minimal Activity & Martial Artists	<0.001			
Years Training	Martial Artists & Athletes	0.946	212.094	2	0.189
	Athletes & Minimal Activity	<0.001			
	Minimal Activity & Martial Artists	<0.001			
Training Frequency	Martial Artists & Athletes	0.840	568.424	2	0.107
	Athletes & Minimal Activity	<0.001			
	Minimal Activity & Martial Artists	<0.001			

Table 1 – ANOVA Test Results

Type of Martial Arts	Number of Participants
Jiu-Jitsu	29
Judo	3
Cuong Nhu	3

Kickboxing	2
Tai Chi	2
Muay Thai	3
Karate	3
Taekwondo	2
Mixed Martial Arts	8

Table 2. The Number of Participants that Trained in Each Martial Art

Discussion

Due to the significant difference ($p = 0.05$) between the three experimental groups, it was determined that exercise type has a role in increasing working memory. After analyzing the graphs, it was evident that martial artists had the highest average digit span score (6.32), compared to the lowest score of 5.79 for participants who did minimal physical activity. These results are similar in other studies analyzing the effects of martial arts.

While martial arts have been found to increase memory, it is difficult to isolate the effect of martial arts on working memory. The effect of martial arts on digit span score may be a result of an accumulation of other factors and variables such as education and intensity of training. One who trains in martial arts every day for a year compared to one who trains in martial arts sparingly for over five years may have different levels of working memory. It is difficult to determine if frequency or length of training has a more significant difference in working memory. While participants were asked the frequency and the number of years they have been training in martial arts or exercise, the results were unclear. This was due to insufficient participants in each category. Participants were only divided based on their exercise type, so the imbalance of participants who trained once a week versus three times a week was significant. However, according to other studies, frequency has a larger influence on cognition compared to length of training (Chuang, 2023). With a larger sample size, and recruitment of participants with different lengths and frequency of training, it may be possible to replicate this study and gain information regarding if frequency or length had a larger or no effect on working memory.

Another key variable in this study that may influence working memory was the sex of the participants. While there was a similar distribution of males and females in the study, there was not an exact division. If this study was performed by having an equal number of males and females in each category, this variable could be better understood. Based on the collected data, there was no significant difference in digit span score between males and females in either experimental group. However, it has been found that male martial artists have a lower level of psychomotor speed and cognition compared to female martial artists (Bennett,

2020). While female martial artists outperformed males and received higher digit span scores than male martial artists, the results were not significant ($p > 0.05$). However, there was a disproportionate amount of males and females in the martial arts group (32 males and 18 females). The results may be skewed due to this disparity, so it is not clear if female martial artists would have a higher increase in working memory compared to male martial artists.

Education is a key variable that may affect the entire results of the experiment. It is crucial to analyze this variable since typically students with a higher education have an increased working memory compared to those with a lower level of education (Guerra-Carrillo, 2017). Due to the disparity of participants in each level of education, it was unclear if education was a significant variable in this study. There were 69 total participants who completed some college, which is the vast majority of participants. However, this may have been beneficial to the study since the educational differences in the participants were limited to mainly college students. The exact results were unclear. When comparing the differences in digit span score to educational level, there was no significant difference, so it may not have had greatly influenced the resulting data and conclusions of this study. Age is also correlated to education since older participants would be more likely to complete higher levels of education compared to younger participants. The age of the participants ranged from 18 to 30, and the mean was 22. This also mirrors why the majority of participants only completed some college. Due to the wide range of ages, it was difficult to determine if it played a large impact on digit span score. The impact may be similar to the impact that education played in this specific research study.

Mental health and self-esteem are significant variables in a large percentage of experiments involving human participants. It may cause false positives or negatives to affect an individual's level of confidence. If a person is predisposed to a negative statement, they may perform poorly as a result of receiving negative feedback (Jung Kim, 2019). If the participants automatically assumed martial artists would outperform them if they performed minimal physical activity, they may automatically not provide as much effort or perform poorer than if they were not told the goal of the experiment prior to beginning the test. If minimal information was provided at the beginning of the study, this may limit the predisposition of the participant prior to their digit span test. When analyzing the results of perceived working memory, there was a significant difference between the participants that were physically active and those who performed minimal physical activity. The greatest difference was between martial artists and those who did minimal physical activity. Martial artists reported higher levels of perceived memory compared to the minimal physical activity group, which may indicate a higher sense of self-confidence and self-esteem. However, athletes had a similar level of perceived

memory compared to martial artists. Therefore, remaining physically active may increase a person's self-esteem and confidence level.

After analyzing the data and determining that martial artists had a higher working memory capacity, the question of whether this was due to physical strength or cognitive skill remained unanswered. While martial artists require high endurance, strength, and speed to execute martial arts techniques, people who exercise often undergo similar training. However, the key difference between weight training and martial arts training is the skill required to analyze, strategize, and execute martial arts techniques. In Brazilian Jiu-Jitsu, there are hundreds of techniques that an athlete is expected to incorporate and execute while sparring with a training partner to gain a control and a submission in a limited amount of time.

There are many neurobiological mechanisms that are intertwined to allow working memory to function. One of the regions that is known to be activated during working memory is the prefrontal cortex. It has been determined through fMRI imaging that prefrontal cortex activity is both necessary and sufficient for working memory function (Riley, 2016). This region is crucial since it is responsible for making decisions regarding the manipulation of information that has been obtained. Furthermore, it has also been found through computed tomography that the superior parietal cortex is instrumental and activated when manipulating data is received from working memory (Koenigs, 2009). While the hippocampus is historically known for long-term memory, it has also shown to be involved in working memory. It was determined that the hippocampus is involved in global visual changes instead of discrete visual changes for working memory (Yonelinas, 2024). It has also been established that the basal ganglia receive projections from dopaminergic nuclei that allow for working memory function (Vigneswaran, 2023). Dopamine has been found to be crucial in regulating working memory. Specifically, it has been located in the deep layer PFC pyramidal neurons in the prefrontal cortex, which has been associated with prolonged activity when performing working memory tasks (Surmeier, 2007). Lastly, neural oscillations, which are rhythmic patterns of activity occurring in the brain, have been observed to be heightened through high-density electroencephalography during working memory tasks (Semprini, 2021). Exercise has been found to heighten these neural oscillations which increases working memory (Chaire, 2020). Different types of exercises have been shown to have different affects on working memory. For example, there are two distinct forms of exercises such as open-skill exercises, which includes badminton, tennis, and table tennis, and closed-skill exercises such as cycling, jogging, and swimming (Chen, 2019). The difference between these two types of exercise is that open-skill exercises require a higher cognitive skill in order to respond to external stimuli such as the response of another player. Closed-skill

exercises are performed individually and do not require this skill. Through fMRI scans, it was observed that open-skill exercise types have more activation in various brain regions and show an improvement of working memory compared to closed-skill exercise groups. Since martial arts is an open-skill type of exercise, this may be the cause for the increase of working memory. Furthermore, weightlifting, which was performed in the athlete group, is considered a closed-skill exercise. As a result of the difference in exercise type, it may have been the cause for the difference in working memory. Future studies should be performed that compare the working memory of different types of open-skill exercises or different types of martial arts to determine if there are noticeable differences.

Implications for Education

If people who train in martial arts have a substantially better memory than those who only exercise, martial arts could be incorporated and reinforced more in childhood and our daily lives. For example, it could be incorporated into schools to help improve the memory of young children to allow them to perform better in school and become more successful. By incorporating martial arts into the school curriculum, students can become more physically fit and improve their memory simultaneously. This may allow students to grow their memory and perform better in class. Additionally, while it was not analyzed in this study, martial arts have been studied for their positive effects on coordination and motor skills. These skills are crucial for young children to develop over time and should be reinforced.

While martial arts are important for improving memory in young children, they can also be important in elderly patients. Many patients diagnosed with dementia and other neurodegenerative diseases should reinforce martial arts into their routine. While it may be too difficult to perform for patients with advanced Alzheimer's or dementia, predisposed patients should actively train in martial arts. This may delay the disease from progressing sooner or decrease the severity of the disease. A future study should be conducted to analyze the effect of martial arts on predisposed or diagnosed patients with neurodegenerative diseases.

Additionally, it could be an instrumental way to improve memory in people with neurodevelopmental disorders such as autism, attention-deficit/hyperactivity disorder (ADHD), and cerebral palsy. Children with these diseases are at a disadvantage in many school environments due to learning delays. Martial arts may allow them to increase their memory and ability to function better in school. In previous studies, martial arts have been found to improve coordination. Therefore, in patients with deficits in motor skills, martial arts may help improve their functioning and prevent their condition from worsening.

Limitations and strengths

A limitation of this study was that it was not performed in person. Since the survey and digit span test were conducted online, it could have potentially introduced additional variables. For example, the researchers were unable to monitor or observe the participants' behavior as they completed the test. Furthermore, if a participant completed the test in a busy or loud location, their results may have been affected compared to if they had completed it in a quiet location where they could focus. Additionally, if a participant stopped the memory test early due to a distraction, it would decrease their score. Since the survey and digit span test were accessible through an online link, the participants had the option to complete it on any device such as a phone, tablet, or computer. This adds further variables in the compatibility of the test with the device they used, and the user's preference. Furthermore, if a participant received assistance from another person during the memory test, it would alter their results. Also, if participants had taken the digit span test previously, they may have performed better than those who had never taken it before. Future studies should address this issue by having all the participants complete the test in the same room and device under the supervision of a researcher.

Another limitation with this experiment was that the majority of participants in the martial arts group trained in Brazilian Jiu Jitsu. This unproportioned discrepancy was significant, which added another variable to the experiment. Future studies should have an equal amount of participants who train in different types of martial arts. This would withdraw the question if the results were due to participants training in specifically Brazilian Jiu Jitsu or martial arts as a whole. Certain martial arts may strengthen working memory more than other types. If Brazilian Jiu Jitsu strengthens working memory more than other martial art types, this could cause a significant impact in the results compared to if other martial art types were analyzed. Future studies could be performed where the working memory of two separate martial arts groups were analyzed. For example, one group that trains Brazilian Jiu Jitsu and another group that trains in Judo. This could possibly determine if there is a difference in working memory depending on the type of martial arts that is trained or if there is a universal effect from training in martial arts.

Furthermore, another limitation was the frequency with which a participant performed martial arts. The results could vary if a participant had only been training for a year but trained 5 – 7 times a week compared to a participant who had been training for over 5 years but only trained 1 time per week. It is unclear if the length of time or how often a participant trains in martial arts has a larger significance to their improvement in working memory.

After analyzing the data, there was a significant ANOVA result, yet the post hoc tests were not significant. This discrepancy was most likely due to the level of sensitivity between the ANOVA and the post-hoc tests. A future study with a larger sample size could elucidate pair specific effects or if this was a result of a study design limitation.

However, the strength of allowing the test to be performed online was that it decreased the time spent searching for participants. Furthermore, participants may have felt more comfortable answering questions and performing the test on their own compared to being monitored by a research assistant. If the participant is being watched by a research assistant, it may cause them to feel nervous and perform poorly on the exam. The test also provided a wide range of data such as speed when answering questions, accuracy of memory test, educational background, and frequency of exercise type. This allowed for the collection and creation of multiple graphs and charts.

Conclusion

Martial arts can be an instrumental way to improve working memory. While people who exercise still outperformed those who do not exercise, people who train in martial arts had the best score out of the three groups. With an average of 6.32 numbers memorized in a sequence, people who trained in martial arts were able to develop a better working memory than those who only exercised or did not perform any rigorous physical activity. The average digit span for people who only exercised was 5.88 and the average for people who did minimal physical activity was 5.79. There was also a significant difference in perceived memory ($p < .001$) between groups. Additionally, martial artists reported they had a higher perceived memory compared to those who exercise and those who did minimal physical activity. Therefore, there could be a correlation between martial arts and higher self-confidence and self-esteem. Furthermore, there was a statistical difference between the ratio of males and females in the different experimental groups. It is unclear if the greater percentage of males in the martial arts group and the greater percentage of females in the exercise group impacted the results of the experiment. Overall, there was no statistical difference when comparing the scores between age, education level, length of training, and training frequency in the three experimental groups. Since there was no significant difference in training length and frequency between martial artists and those who exercise, this could show that the presence of martial arts training is significant ($p = .05$) in increasing working memory. As a result of this data, martial arts could be incorporated and reinforced more into our daily lives to improve working memory.

References:

Alesi, M., Bianco, A., Padulo, J., Vella, F. P., Petrucci, M., Paoli, A., Palma, A., & Pepi, A. (2014). Motor and cognitive development: the role of karate. Muscles, Ligaments and Tendons Journal, 4(2), 114.

Bennett, L. L., Stephen, S. J., Bernick, C., Shan, G., & Banks, S. J. (2020). Sex moderates the relationship that number of professional fights has with cognition and brain volumes. Frontiers in Neurology, 11. https://doi.org/10.3389/fneur.2020.574458

Chaire, A., Becke, A., & Düzel, E. (2020). Effects of physical exercise on working memory and attention-related neural oscillations. Frontiers in Neuroscience, 14, 239. https://doi.org/10.3389/fnins.2020.00239

Chen, F.-T., Chen, Y.-P., Schneider, S., Kao, S.-C., Huang, C.-M., & Chang, Y.-K. (2019). Effects of exercise modes on neural processing of working memory in late middle-aged adults: An fMRI study. Frontiers in Aging Neuroscience, 11, 224. https://doi.org/10.3389/fnagi.2019.00224

Chuang, I.-C., Chen, I.-C., Su, K.-H., Wu, Y.-R., & Wu, C.-Y. (2023). The effects of high versus low frequency of combined physical and cognitive training on cognitive function in older adults with cognitive decline: a quasi-experimental study. BMC Geriatrics, 23(1). https://doi.org/10.1186/s12877-023-03802-8

Daniel, M. (2016, March 1). The history of Martial Arts. Beemat. https://www.beemat.co.uk/blogs/beemat/120253575-the-history-of-martial-arts

Guerra-Carrillo, B., Katovich, K., & Bunge, S. A. (2017). Does higher education hone cognitive functioning and learning efficacy? Findings from a large and diverse sample. PloS One, 12(8), e0182276. https://doi.org/10.1371/journal.pone.0182276

IBM Corp. Released 2023. IBM SPSS Statistics for Windows, Version 29.0.2.0 Armonk, NY: IBM Corp

Koenigs, M., Barbey, A. K., Postle, B. R., & Grafman, J. (2009). Superior parietal cortex is critical for the manipulation of information in working memory. The Journal of Neuroscience: The Official Journal of the Society for Neuroscience, 29(47), 14980–14986. https://doi.org/10.1523/jneurosci.3706-09.2009

Li, K., Dong, G., & Gao, Q. (2023). Martial arts enhances working memory and attention in school-aged children: A functional near-infrared spectroscopy study. Journal of Experimental Child Psychology, 235(105725), 105725. https://doi.org/10.1016/j.jecp.2023.105725

Loprinzi, P. D., Roig, M., Etnier, J. L., Tomporowski, P. D., & Voss, M. (2021). Acute and chronic exercise effects on human memory: What we know and

where to go from here. Journal of Clinical Medicine, 10(21), 4812. https://doi.org/10.3390/jcm10214812

Ludyga, S., Mücke, M., Leuenberger, R., Bruggisser, F., Pühse, U., Gerber, M., Capone-Mori, A., Keutler, C., Brotzmann, M., & Weber, P. (2022). Behavioral and neurocognitive effects of judo training on working memory capacity in children with ADHD: A randomized controlled trial. NeuroImage. Clinical, 36(103156), 103156. https://doi.org/10.1016/j.nicl.2022.103156

Moore, B., Dudley, D., & Woodcock, S. (2020). The effect of martial arts training on mental health outcomes: A systematic review and meta-analysis. Journal of Bodywork and Movement Therapies, 24(4), 402–412. https://doi.org/10.1016/j.jbmt.2020.06.017

Riley, M. R., & Constantinidis, C. (2016). Role of prefrontal persistent activity in working memory. Frontiers in Systems Neuroscience, 9. https://doi.org/10.3389/fnsys.2015.00181

Semprini, M., Bonassi, G., Barban, F., Pelosin, E., Iandolo, R., Chiappalone, M., Mantini, D., & Avanzino, L. (2020). Modulation of neural oscillations during working memory update, maintenance, and readout: An hdEEG study. Human Brain Mapping, 42(4), 1153–1166. https://doi.org/10.1002/hbm.25283

Stoet, G. (2010). PsyToolkit - A software package for programming psychological experiments using Linux. Behavior Research Methods, 42(4), 1096-1104.

Stoet, G. (2017). PsyToolkit: A novel web-based method for running online questionnaires and reaction-time experiments. Teaching of Psychology, 44(1), 24-31.

Suetake, V. Y. B., Franchini, E., Saraiva, B. T. C., da Silva, A. K. F., Bernardo, A. F. B., Gomes, R. L., Vanderlei, L. C. M., & Christofaro, D. G. D. (2018). Effects of 9 months of martial arts training on cardiac autonomic modulation in healthy children and adolescents. Pediatric Exercise Science, 30(4), 487–494. https://doi.org/10.1123/pes.2017-0083

Surmeier, D. J. (2007). Dopamine and working memory mechanisms in prefrontal cortex. The Journal of Physiology, 581(Pt 3), 885. https://doi.org/10.1113/jphysiol.2007.134502

Vigneswaran, Nair, S. S., & Chakravarthy, V. S. (2023). A basal Ganglia model for understanding working memory functions in healthy and Parkinson's conditions. In bioRxiv (p. 2023.07.04.547640). https://doi.org/10.1101/2023.07.04.547640

Yonelinas, A., Hawkins, C., Abovian, A., & Aly, M. (2024). The role of recollection, familiarity, and the hippocampus in episodic and working

memory. Neuropsychologia, 193(108777), 108777. https://doi.org/10.1016/j.neuropsychologia.2023.108777

What is Taekwondo? (2017, May 2). World Class Taekwondo; Master Chong's World Class Tae Kwon Do. https://buffalotkd.com/what-is-tae-kwon-do/