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The Effects of Acute Bouts of Aerobic and Resistance Exercise on Neuroplasticity

Michael Shafer
ms781646@wcupa.edu

The Effects of Acute Bouts of Aerobic and Resistance Exercise on Neuroplasticity

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Dedication

Dedicated to all those who supported and believed in me.

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Abstract

Neuroplasticity takes place when acquiring new skills, after damage to the nervous system, and as a result of sensory deprivation (5). It can also take place due to exercise (11)(22). Few studies exist that look at the effects of anaerobic/resistance training and its effects on Neuroplasticity in humans, as the majority of research found delves into how resistance training can help at the subcortical and spinal level of the body, not in the brain (1). The aim of this study was to determine whether resistance training is as effective as aerobic training at improving neuroplasticity. Five competitive Weightlifters (3 females, 2 males, age 34±9) were recruited to complete a control, aerobic, and resistance acute protocol. The subjects completed the Trail-Making Test (TMT) before and immediately after the cessation of each 20-minute protocol separated by multiple days. A repeated measures ANOVA for part A revealed a significant effect of time (pre-post $p=0.004$) and condition (control, aerobic, and resistance, $p=0.004$) for part A, but there was not a statistically significant interaction between timepoint and condition ($p=0.429$). A separate ANOVA revealed a significant effect of time (pre-post $p=0.033$) but not condition (control, aerobic, and resistance $p=0.054$) for part B, but there was not a statistically significant interaction between timepoint and condition ($p=0.164$). Our results are in agreeance with prior research, but show promise that resistance exercise may be as beneficial as aerobic exercise and needs further research.

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1.Review of the Literature

Background

Our understanding of the human body is ever advancing, thanks to the tireless work of researchers and the advances of scientific processes and instruments. The concept of neuroplasticity, once thought impossible (2), is no exception to this advancement as the field has enjoyed many leaps and bounds forward since Santiago Ramon y Cajal coined the term "neuronal plasticity" (3) after discovering nonpathological changes in the structure of adult brains in response to external stimuli. This once perceived impossibility, lingers to this day in the Merriam-Webster definition of the word, which is, "the capacity of the brain to develop and change throughout life, something Western science once thought impossible." (4). Bavelier and Neville take this one step further adding that neuroplasticity is the ability of the nervous system to change its organization in response to the demands placed on it by internal and external factors (5). Neuroplasticity takes place when acquiring new skills, after damage to the nervous system, and as a result of sensory deprivation (5). One specific subdivision of neuroplasticity combines the fields of Neuroscience and Exercise Physiology.

The literature is strongly in support of the beneficial effects of physical exercise on neuroplasticity and cognition, as is reported by Kirsten Hötting and Brigitte Röde, who compiled research on the subject of exercise and neuroplasticity (5). Their systematic review revealed that exercise had many beneficial effects on cognitive function as well as an enhancement of neural systems.

Defining exercise

Neuroplasticity has been studied at different organizational levels of the nervous system and there are many hypotheses as to what may be driving the changes. The current review will focus on the demonstrable effects of exercise on cognition and neuroplasticity on the gross scale. The main variable of interest is the behavior outcomes demonstrating that the process of neuroplasticity has occurred. There are several physical activities that have been shown to enhance neuroplasticity, however the addition of extra stimulation after exercise, such as a cognitive test, has been demonstrated to lead to a higher likelihood of neuroplasticity occurring (6). Physical activity is any movement produced by muscles that requires energy expenditure and is performed in an organized fashion with a deliberate outcome. (7) Exercise, a subcategory of physical activity, is planned, structured, repetitive, and deliberate to improve or maintain one or more components of physical fitness. This review will focus specifically on exercise as it relates to neuroplasticity (7).

Study Design

Over the past few decades, there has been mounting evidence suggesting better cognition, memory, and academic performance in individuals who are physically active compared to sedentary individuals (8). Indeed, many studies demonstrate a link between physical fitness/exercise and cognitive function (4) (27). In a meta-analysis of nearly 200 studies, Etnier et al (9) concluded that both acute and long-term exercise improved cognition. Furthermore, a sub analysis of 44 studies in children echoed these findings (10). While it is not possible to determine causation from these cross-sectional studies, these strong results do suggest a correlation that warrants a more comprehensive investigation utilizing controlled, experimental design studies.

Intervention or experimental design studies can be either acute or chronic. In an acute study, the experimenters measure the subject's cognitive performance immediately before and after a single exercise session. A chronic study can last from a few short weeks to many months. When conducting a chronic protocol, subjects are given a regimen to perform a certain number of times per week and the dependent variable (usually neuroplasticity or cognition) is tested several times throughout the process and finally at the conclusion of the study. As the current study is acute in nature, this review will focus on the acute effects.

Mechanisms behind Neuroplasticity and Testing

Animal and human studies confirm that regular exercise enhances physical and mental health throughout the lifespan (7). Due to its highly responsive nature to exercise, the hippocampus has been of particular interest to researchers. The hippocampus is critically involved in learning and memory and is one of two regions in the mammalian brain that continues to grow new neurons throughout the lifespan (11). Exercise has been shown to attenuate the age-related decline of the hippocampus (11) and can ameliorate many neurodegenerative diseases by increasing hippocampal neurogenesis and activating a multitude of molecular mechanisms promoting brain health (10).

In a 2004 study, researchers found evidence to support that resistance training specifically can alter the input-output properties of the corticospinal pathway, which can increase the speed of processing/reaction via increased speed of afferent and efferent signaling in humans. (12). In rodents, it has also been shown that voluntary exercise increases Brain-derived neurotrophic factor (BDNF) and other neurological components that promote plasticity (13). BDNF is a protein that is found in the brain and spinal cord that is promotes survival of nerve cells (neurons) by playing a key role in their growth, maturation, and maintenance. In the brain, BDNF proteins are active at the connections between neurons (synapses), where they promote synaptic plasticity (neuroplasticity) by strengthening existing connections while helping to create new connections (14). BDNF may play a key role in neuroplasticity in animals (15) (16), as well as healthy adult (13) (17) and diseased/injured populations (18) (19) (20). A separate animal study utilizing older rats demonstrated that 8 weeks of both aerobic and strength training improves spatial memory and neural plasticity by increasing neurotrophic and glutamatergic signaling(19). Furthermore, these brain-level changes were all observed in the Hippocampus (21).

Research done by Petzinger et al. (22), supports the role of exercise in modulating dopamine (DA) and glutamate neurotransmission, synaptogenesis and increased regional cerebral blood flow. This study was carried out on a specific population of patients with Parkinson's Disease (PD), and showed that both "skilled" and aerobic exercise have positive effects on our brain's plasticity. Furthermore, "skilled" exercise, classified as goal-oriented movement having an importance on temporal and/or spatial accuracy, can effect frontal related circuits while aerobic exercise had a more global effect around the brain (20).

This suggests that there are many possible pathways in which exercise can positively affect the brain and its ability to remain plastic through life, disease, and damage. Moreover, current evidence also supports that acute bouts of exercise can lead to improvements in discrimination tasks (23) as well as increases in BDNF and blood flow (24), although the serum levels in long term trained individuals is lower (25). One may speculate that lower serum levels could infer that more is being utilized than normal, and thus less is free-flowing. Conversely, lower BDNF observed in trained individuals could be because less BDNF is needed to elicit the same response as untrained individuals.

Testing Neuroplasticity

Many tests exist in the research that can be used to assess acute neuroplastic changes, the gold standard of which is functional Magnetic Resonance Imaging (fMRI). fMRI measures brain activity by imaging changes in blood flow assuming that cerebral blood flow and neural activation are coupled (26). However, fMRI is often very costly and time consuming. Additionally, it could lead to patient discomfort due to fear of confined spaces. Thus, a more simple, yet validated method to immediately assess that observable change has occurred is the Trail-Making Test (TMT) (27). The TMT is a validated (28) and effective way to test task-switching and other abilities (28) and is used clinically for assessing brain damage (29). There are well established instructions (30) and normative and stratified data for nearly every group including those of interest to this study (31). It was initally part of the Army's Individual Test Battery (32) and was later incorporated into the Halstead-Reitan Battery (33). Benefits of this test include ease of use, requiring only a paper and pen, short instructions, and quick replicability. These user-friendly properties as well as the decades of research will allow me to use this with confidence.

Evidence in Support of Exercise-Induced Neuroplasticity

When an individual exercises, the arousal of that exercise can help improve cognitive task performance, specifically by improving rapid decisions and enhancing memory storage retrieval (34). Though responses vary from one individual to another, it is generally understood that exercise activates the Sympathetic Nervous System (SNS) while inhibiting the Parasympathetic Nervous System (PNS) (35). It is speculated that the increase in SNS activity, which releases many excitatory and reward-based hormones and chemicals, (dopaminergic, catecholamines, etc.) may be the source of arousal which enables brain plasticity to occur more effectively (10). In a review of studies investigating the effects of acute bouts of exercise on adults' cognitive performance (36), Tomporowski et al. separated participants into three separate groups. The first group focused on the construct of fatigue, including studies that used brief, maximal exercise protocols. The second group focused on the construct of arousal and used both maximal and submaximal bouts of short duration. The final group focused on the effects of submaximal exercise of long duration. Tomporowski's studies showed that exercise can enhance response speed and accuracy as well as facilitate cognitive processes that are important to problem-solving and completion of goal-oriented action. A similar result was found by McMorris and Graydon (37) in their meta-analysis of available research suggesting that exercise had a positive effect on cognitive processing.

Simple and complex tasks alike have been shown to improve in direct studies (38). Early research by McGlynn et al. (23) showed that exercise helped to improve cognitive function and neuroplasticity based on a simple discrimination task. Another study by Chmura et al. looked at the relationship of choice reaction time during exercise (39). Chmura et al. observed that the reaction time dropped while cycling, but then increased past pre-exercise levels by 18% immediately after cycling, thus suggesting that the relationship between reaction time and plasma catecholamines fits a U shape curve by starting at a certain level, decreasing, and then increasing again (39).

An interesting study was done by Brisswalter et al. (40) where they tested simple reaction times while the subject was performing a task (cycling) and found an improvement (decrease) in reaction time compared with the same participants in a control condition (not cycling). Another study looked at a line-matching test that was given to 15 female subjects while they were exercising on a motor-driven treadmill. The accuracy and speed were recorded for four different 3-minute stages of exercise. The researchers found that the subjects did not improve in any of the stages except the final one. Further, the post-exercise test showed significantly greater improvement than the first three stages (41).

Gaps in the Literature and other Modalities

Thus far, the majority of research involving resistance training focuses on the effects at the subcortical and spinal level of the body, and not in the brain (1). The anaerobic/resistance part of such studies usually fall secondary to aerobic. As such, the field would benefit from investigating this type of exercise.

It is possible that resistance and anaerobic training may lead to enhanced Neuroplasticity due to the task complexity model (42) that states that the "complex motor tasks involving in-depth cognitive processing promote neuroplastic changes sub serving skillful motor performance (42)". In the commonly studied aerobic mode of exercise, participants are performing simple motor tasks, such as cycling on a cycle ergometer or jogging on a treadmill. This contrasts with the complex motor tasks of resistance training and other anaerobic workouts and may be a basis for enhanced plasticity outcomes.

Many neural adaptations to resistance training are already well known, such as twitch and reflex improvement (43), as well as studies of neuroplasticity in adults using non-traditional methods of skilled exercise such as dancing (44) which demonstrates improvements in exoskeletons for stroke patients (45). Another study that took an overview approach on animal models concluded that the type of exercise may have regional effects on brain circuitry in the basal ganglia, with skilled exercise affecting frontal related brain regions differently and more so than pure aerobic exercise. (22). This shows that researchers have grounds for focusing on other modalities rather than just pure aerobic exercise and comparing the different approaches to exercise.

Conclusion

Despite the wealth of knowledge gained over the past few decades which has allowed the field of neuroplasticity to go from something deemed impossible past the juvenile period (2), to a well-documented phenomenon, there has been little exploration into the word of resistance training and anaerobic exercise in relation to neuroplasticity. It remains to be determined whether any benefits stem from this type of protocol; however, given the review of the literature, it seems plausible that it may be as effective as aerobic training. This is important in regards to the benefits it may elicit (43) as well as for the individuals who simply prefer resistance training to other training modalities but would still benefit from potential plasticity benefits.

2.Introduction

Our understanding of the human body is ever advancing, thanks to the tireless work of researchers and the advances of scientific processes and instruments. The concept of neuroplasticity, once thought impossible (1), is no exception to this advancement as the field has enjoyed many leaps and bounds forward since Santiago Ramon y Cajal coined the term “neuronal plasticity” (2) after discovering nonpathological changes in the structure of adult brains. This once perceived impossibility lingers to this day in the Merriam-Webster definition of the word, which is, “the capacity of the brain to develop and change throughout life, something Western science once thought impossible.” (3). There has been much progress with a vast amount of research that leads down many different avenues in the field. One such of these subdivisions marries the fields of Neuroscience and Exercise Physiology. Bavelier and Neville also provide a better working definition of neuroplasticity to use going forward in the ability of the nervous system to change its organization to different demands places on it by internal and external factors (5). Neuroplasticity takes place when acquiring new skills, after damage to the nervous system, and as a result of sensory deprivation (5).

Prior research, which this work will stand on the shoulders of, also expanded neuroplasticity and its applications to all improvement that occurs due to neuronal adaptations, implied or directly seen. The prior research called improvements that are seen from exercise, even indirect observations such as discrimination task improvement neuroplasticity (22). These changes can be called neuroplasticity because of past studies found direct links between brain changes and these behaviors. In a 2004 study, researchers found evidence to support that resistance training specifically can alter the input-output properties of the corticospinal pathway, which can increase the speed of processing/reaction via increased speed of afferent and efferent signaling in humans. (12).

In rodents, it has also been shown that voluntary exercise increases Brain-derived neurotrophic factor (BDNF) and other neurological components that promote plasticity (13). BDNF is a protein that is found in the brain and spinal cord that is promotes survival of nerve cells (neurons) by playing a key role in their growth, maturation, and maintenance. In the brain, BDNF proteins are active at the connections between neurons (synapses), which is where this BDNF promotes synaptic plasticity (neuroplasticity) by strengthening existing and helping to create new connections (14). BDNF seems and may play a key role in neuroplasticity, in animals (15), (16), healthy populations (13), (17), as well as diseased/injured populations (18), (19), (20). Another animal study utilizing older rats demonstrated that 8 weeks of both aerobic and strength training improves spatial memory and neural plasticity by increasing neurotrophic and glutamatergic signaling (19). Further, these brain-level changes were all observed in the Hippocampus (21).

Few studies exist that look at the effects of anaerobic/resistance training and its effects on Neuroplasticity in humans, as the majority of research found delves into how resistance training can help at the subcortical and spinal level of the body, not in the brain (1). The anaerobic/resistance part of such studies usually fall secondary to aerobic. This being said, the field would benefit from looking into this area of exercise, as it seems there is already a vast amount of work done in the aerobic field.

It is possible that resistance and anaerobic training may lead to enhanced Neuroplasticity due to the task complexity model (42) that states that the “complex motor tasks involving in-depth cognitive processing promote neuroplastic changes sub serving skillful motor performance

(42)”. In the commonly studied aerobic mode of exercise, participants are performing simple motor tasks, such as cycling on a cycle ergometer or jogging on a treadmill. This contrasts with the complex motor tasks of resistance training and other anaerobic workouts and may be a basis for enhanced plasticity outcomes.

Many neural adaptations to resistance training are already well known, such as twitch and reflex improvement (43) as well as studies of neuroplasticity in adults using non-traditional methods of exercise such as dancing (44) demonstrating improvements in exoskeletons for stroke patients (45). Another study that took an overview approach on animal models concluded that the type of exercise may have regional effects on brain circuitry in the basal ganglia, with skilled exercise affecting frontal related brain regions differently and more so than pure aerobic exercise. (22). This shows that researchers have grounds for focusing on other modalities rather than just pure aerobic exercise and comparing the different approaches to exercise.

The field of Neuroplasticity has gone from something impossible past the juvenile period (2), to well-documented, but there has been little investigation in resistance training and anaerobic exercise and their association to neuroplasticity. It remains to be determined whether any benefits stem from this type of exercise; however, it is plausible that it may be as effective as aerobic training. This would be important to know for the other benefits it has (43) as well as for the individuals who simply prefer it to other training modalities and would still like the plasticity benefits that come with aerobic training.

The research question is whether resistance training is as effective as aerobic training at improving neuroplasticity. The hypothesis is that resistance training will be as effective as aerobic training. This could be due to a few different factors; the increased stimulation (20), neural adaptation (44), task-complexity model (43), or increased BDNF (12) with a similar mechanism to aerobic training.

3.Methods

Participants:

3 females and 2 males (*n*=5) were recruited via the Lehigh Valley Barbell Club which consists of a population of competitive weightlifters. Email addresses of the athletes at the Lehigh Valley Barbell Club were obtained from the Head Coach and point of contact for the Barbell Club. Participants received an email inviting them to take part in this study. Participants were provided with a copy of the informed consent prior to the first session to allow for thorough review. Researchers reviewed the consent with the prospective participant at the first meeting and answered any questions before signing. Upon consent, participants were given a PAR-Q+ (updated January 2020) to confirm inclusion/exclusion criteria. In order to participate, subjects must have participated in a Weightlifting competition within the past year and must also be physically active (exercising at least 30 minutes or more 2 times per week for the past 6 months). All subjects were held to the following exclusion criteria: history of known cardiovascular disease, diabetes or other metabolic disease (thyroid, renal, liver), recent chest pain, shortness of breath/dizziness/fainting, pregnancy, or current smoker. Anthropometric and demographic information of participants can be found in Table 1.

Table 1.

Variable	Mean±SD*
Age	34±9
RHR	62±11
Resting Systolic BP**	115±7
Resting Diastolic BP	73±6
Weight (kg)	79.35±22.68
Height (cm)	169.14±9.60

Table 1. Anthropometric and Demographic Information *SD= Standard Deviation **BP= Blood Pressure

Height was assessed using a stadiometer with standard protocols (46). Weight was assessed using a properly certified and calibrated scale using the standard protocols (47). Resting Heart Rate was assessed using a 60-second count and a stopwatch palpated on the radial artery.

The experimental design was acute and crossover in nature with subjects serving as their own control. Subjects completed an informed consent then performed the Trail-Making Test (TMT, example included in appendices) to serve as their control test. On the following visit, at least 48-72 hours later, subjects were randomly assigned to complete aerobic or resistance exercise protocols first. Subject took the TMT, followed by either aerobic or resistance exercise then performed the TMT again. They returned 48-72 hours later to complete the opposite mode of exercise along with a pre and post TMT. Schematic for the visits is Figure 1.

Visit 1 (Control Visit)

TMT Rest 20 minutes TMT

|___________________________|

Visit 2 (Randomized Aerobic or Resistance)

TMT 5 min warm up TMT
15 min Aerobic

|___________________________|

Visit 3 (Randomized Aerobic or Resistance whichever the subject has not completed yet)

TMT 10 min warm up TMT
10 min Resistance

|__________________________|

Figure 1. Schematic for Visit Protocols.

Trail-Making Test: The subject was given one of two randomly selected copies of the Trail Making Test Part A worksheet and a pen. The researcher demonstrated the test to the patient using the sample sheet (Trail Making Part A – SAMPLE). The researcher then then timed the participants with a stopwatch as they follow the “trail” made by the numbers on the test. Time was recorded. The procedure was repeated for Trail Making Test Part B.

Both parts of the Trail Making Test consist of 25 circles distributed over a sheet of paper. In Part A, the circles are numbered 1 – 25, and the participants drew lines to connect the numbers in ascending order. In Part B, the circles included both numbers (1 – 13) and letters (A – L). As in Part A, the subject drew lines to connect the circles in an ascending pattern, but with the added task of alternating between the numbers and letters (i.e., 1-A-2-B-3-C, etc.). The patient was instructed to connect the circles as quickly as possible without lifting the pen from the paper. The subject was timed as they connected the "trail." If the participant made an error, the researcher pointed out the error immediately and allowed the patient to correct it. Errors affected the patient's score only in that the correction of errors is included in the completion time for the task. The test was to be terminated after 5 minutes regardless of test completion. The total number of errors were averaged and mean times to completion was compared between aerobic and resistance exercise as well as compared with control times.

Control Visit (Visit 1): Subjects completed Informed Consent and PAR-Q+, as well as measurement of Resting Heart Rate, Blood Pressure, Height, and Weight. After these data are collected, the subjects completed the TMT and had a 20-minute rest period. At the cessation of the 20-minute rest period the subjects completed the TMT again and the visit concluded.

Aerobic Visit: Participants age-predicted maximum heart rate was calculated using the formula of 220 minus their age. Subjects were then outfitted with a heart rate monitor (Polar USA). Subjects completed the TMT before beginning cycling. Then subjects completed a 5-minute warm up followed by 15 minutes of cycling at 60% of their HR maximum. At the cessation of exercise, subjects completed the TMT again.

Resistance Visit: Participants had a known 3-RM maximum for the Romanian Deadlift using the standard NSCA method for maximum testing from their Weightlifting coach.

Participants performed the RDL exercise at 60% of their calculated 1RM based on the 3-RM test to ensure that the participant was able to complete the protocol. The exercise was performed at intervals of 30 seconds of exercise and 90 seconds of rest. The exercise was performed at the tempo of a metronome set to 32 beats per minute (reps= 8 per 30 seconds), The subject performed 10 total minutes of these intervals, 5 cycles of active and rest periods in succession. The subjects completed a general and specific warm-up to properly prepare the subject for exercise and prevent injury. This warmup took 10 minutes to complete. A Polar brand heart rate monitor will be worn from the beginning of the warmup to completion of the final TMT.

Statistical analysis was performed using Sigma Plot v. 14 (Systat Software, San Jose, CA). A 3x2 repeated measures ANOVA was calculated to determine significance of inter-group relationships. The percent change was calculated from Pre to Post test for control, aerobic, and resistance conditions. A one-way repeated measures ANOVA was performed to determine differences in the percent change from pre to post in control, aerobic, and resistance conditions.

4.Results

Time to completion:

A 3x 2 design repeated measures ANOVA revealed a significant effect of time (pre-post p=0.004) and condition (control, aerobic, and resistance, p=0.004) for part A, but there was not a statistically significant interaction between timepoint and condition (p=0.429, Figure 2).

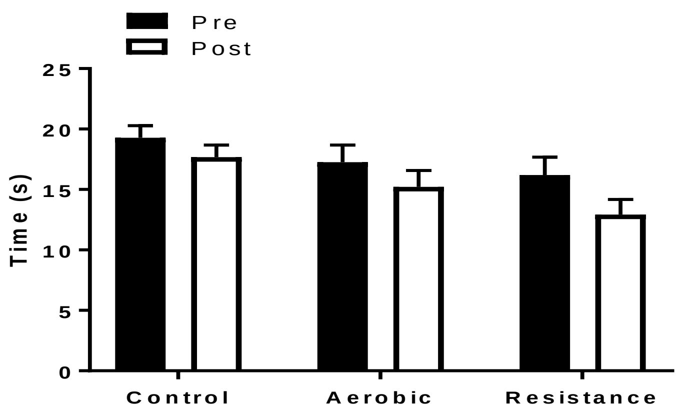

Figure 2. Time to Completion for TMT Test Part A Before and After Intervention

A separate 3x 2 design repeated measures ANOVA revealed a significant effect of time (pre-post p=0.033) but not condition (control, aerobic, and resistance p=0.054) for part B, but there was not a statistically significant interaction between timepoint and condition (p=0.164, Figure 3).

The percent change from pre to post test was not different between conditions for part A or part B (p=0.141 part A, Figure 4; p=0.055 part B, Figure 5).

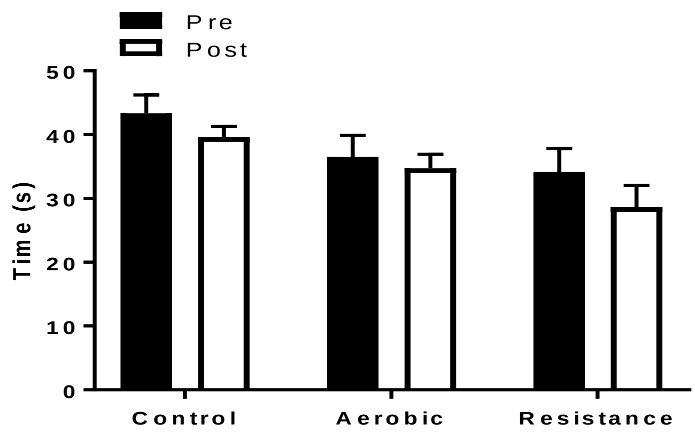

Figure 3. Time to Completion for TMT Part B Before and After Intervention

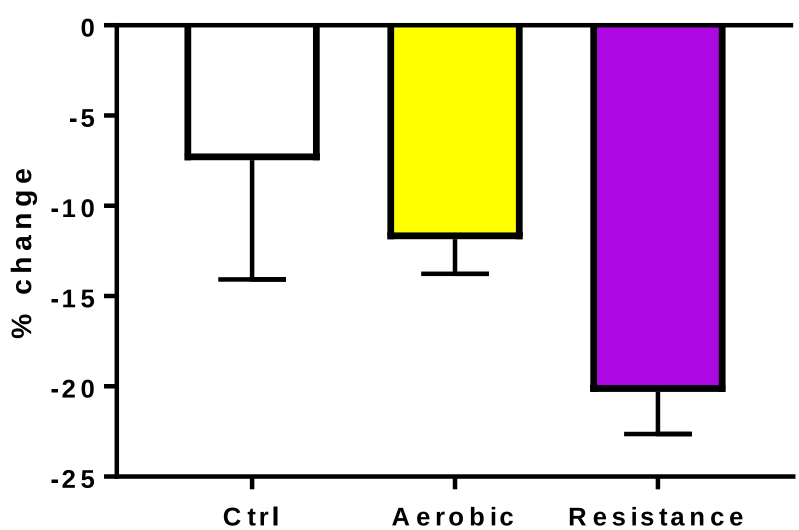

Figure 4. Percent changes for pre- versus post- part A of the TMT

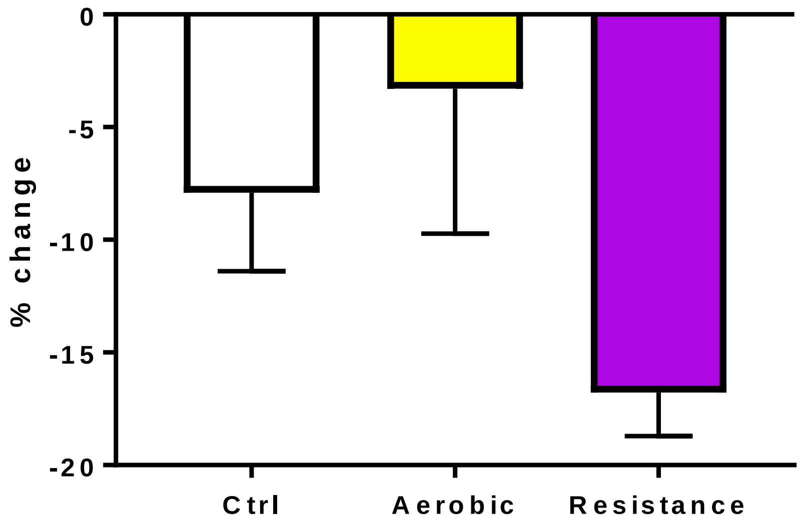

Figure 5. Percent changes for pre- versus post- part B of the TMT

5. Discussion

The purpose of this study was to investigate the effectiveness of resistance exercise in improving neuroplasticity. Thus far, our results suggest that resistance exercise is as effective as aerobic exercise at promoting neuroplasticity as measured by the Trail-Making Test. The 3x2 design repeated measures ANOVA showed that there was a significant interaction between pre- and post- times as well as an effect of resistance and aerobic exercise compared to control, though no significant interaction was found between groups. This supports the notion that resistance exercise has some effect on neuroplasticity.

No significant interaction was found between time point or condition in either part A or B of the TMT (part A $p=0.429$, part B $p=0.164$) however main effects of timepoint and condition were present for part A (Figure 2, $p=0.004$ for timepoint and $p=0.004$ for condition), while a main effect for timepoint was found for part B (Figure 3, $p=0.033$ for timepoint, $p=0.054$ for condition). Additionally, a one-way ANOVA performed on the percent change from pre to post in part A is trending at $p=0.141$ as well as for part B at $p=0.055$. The power of the performed tests was below the desired power of 0.800, thus these measures may reach statistical significance with the addition of more participants.

The mechanisms put forth in the introduction; the increased stimulation (20), neural adaptation (44), task-complexity model (43), or increased BDNF (12) with a similar mechanism to aerobic training are all still valid and plausible after analyzing the results of this study. Another possible mechanism, and one that is favorable to this study, is the idea of exercise-induced arousal. In a meta-analysis (34) researchers found that 20 minutes of cycling improved cognitive task performance, similar to the results of the current study. Comparing the improvement from aerobic exercise and the improvement from resistance exercise, it is demonstrated that this is an area that needs to be investigated more deeply and has much potential.

The findings agree with prior research on aerobic exercise. Countless studies from the review of the literature in Chapter 1 as well as meta-analyses (9) have shown that aerobic exercise improves neuroplasticity in a variety of settings from fMRI (26), to simple reaction time tests (40). The results being statistically significant as well as agreeing with prior studies indicates that exercise's effect on neuroplasticity and cognition.

This study is novel in the fact that it compares a strictly resistance exercise protocol to a strictly aerobic exercise protocol. The existing literature, to the author's knowledge at the time of writing, does not include a study that compares the two. The study examined a group of Weightlifters who had already had experience in resistance training and were competitive in the sport, which could mean that the effect may be even greater in those with a novice training age whose neural adaptations to resistance exercise are just beginning.

The findings are important groundwork for more research into resistance training as a way to improve neuroplasticity for those who prefer it to aerobic exercise. Though aerobic exercise is important and has many positive effects that are well documented, some prefer to partake in resistance exercise. Everyone is unique and the way they improve themselves should be tailored to them. If someone wants to primarily focus on resistance exercise, but still wants all of the brain benefits (cognition, neuroplasticity, etc.) that come with aerobic exercise, this study shows that it is likely that they can attain the same benefits from resistance exercise.

Additionally, several large population cohort studies have shown the importance the role physical activity (exercise) plays in being neuroprotective against cognitive decline and dementia (48). The results of this study are promising contribute to the body of knowledge that resistance exercise has an effect on cognition and neuroplasticity, which would be potentially beneficial to those with early onset neurodegenerative diseases such as dementia, Parkinson's disease, and Alzheimer's disease.

The major limitation of this study is the *n*= 5, which is due in large part to the novel Coronavirus (COVID-19) pandemic. The gym where research was being conducted at was forced to close after only two weeks of data collection, but due to diligent planning, researchers were still able to collect data from 5 subjects completely. Room for future research exists with a larger *n* and a more general population. Right now, the results can only be said for the specific population of competitive Weightlifters, and a general population study done in a similar manner would be able to expand the results to everyone within other populations. Further, use of fMRI or EEG technology, which is not within the scope of a Master's Thesis largely or within the funding constraints would be able to show the changes either in real time (EEG) or directly before and after (fMRI) exercise as a way to further validate the findings. Future researchers have a wide-open field of discovery in the realm of resistance exercise and its association with neuroplasticity.

6.Conclusion

The goal at the outset of this journey was to answer the research question of if resistance exercise is as effective as aerobic exercise at improving neuroplasticity. The study found that, in a population of competitive Olympic-Style Weightlifters, when combining the pre- data and the post- data, there is a difference, but more research is needed with a larger sample size to elucidate the cause. The percent changes from pre- and post- differences are trending in the direction of significance. The means and standard deviation from the data are also promising, with more research and higher sample size also necessary. This is great news for any Weightlifters that they may still get neuroplasticity and cognition benefits even if they prefer to exercise primarily with resistance exercise or if for any other reason are impeded from or simply cannot perform aerobic exercise.

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Appendices

Approval Document for this study from the West Chester University Institutional Review Board

WCU
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Office of Research and Sponsored Programs | West Chester University | Ehinger Annex
West Chester, PA 19383 | 610-436-3557 | www.wcupa.edu

Protocol ID # 20200218B
This Protocol ID number must be used in all communications about this project with the IRB.

TO: Michael Shafer

FROM: Nicole M. Cattano, Ph.D.
Co-Chair, WCU Institutional Review Board (IRB)

DATE: 10/16/2019

Project Title: The Effects of Acute Bouts of Aerobic and Resistance Exercise on Neuroplasticity
Date of Approval: 2/14/2020

☒ **Expedited Approval**

This protocol has been approved under the new updated 45 CFR 46 common rule that went in to effect January 21, 2019. As a result, this project will not require continuing review. Any revisions to this protocol that are needed will require approval by the WCU IRB. Upon completion of the project, you are expected to submit appropriate closure documentation. Please see www.wcupa.edu/research/irb.aspx for more information.

Any adverse reaction by a research subject is to be reported immediately through the Office of Research and Sponsored Programs via email at irb@wcupa.edu.

Signature:

Co-Chair of WCU IRB

WCU Institutional Review Board (IRB)
IORG#: IORG0004242
IRB#: IRB00005030
FWA#: FWA00014155

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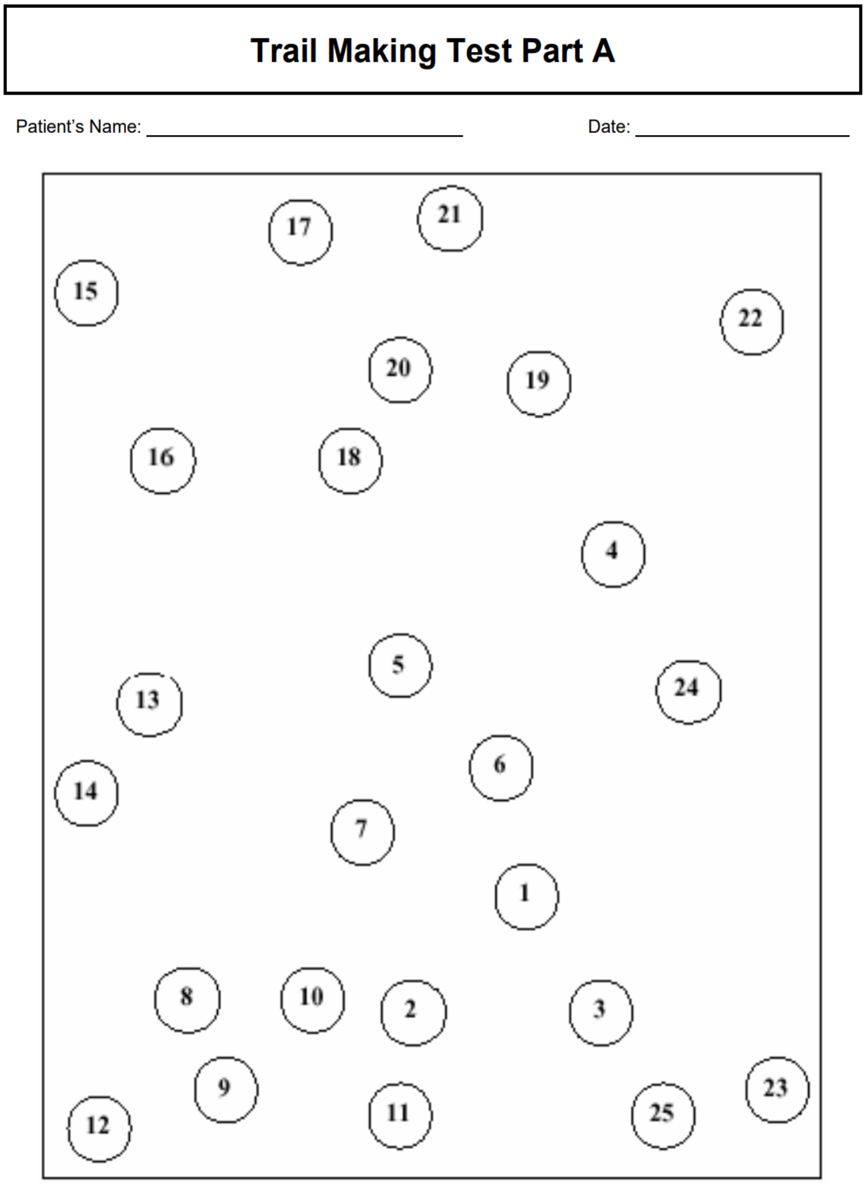
Example of one of the Trail-Making Tests used in data collection



Trail Making Test Part B

Patient's Name: ______________________________ Date: ____________________