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Effects Of Exercise Intensity And Type On Executive Function In Elementary-Aged Children

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EFFECTS OF EXERCISE INTENSITY AND TYPE ON EXECUTIVE FUNCTION IN ELEMENTARY-AGED CHILDREN

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The interactions of exercise on executive functioning (EF) have been studied thoroughly in previous literature, focusing mostly on the interactions of aerobic exercise (AE) intensity and its effects on inhibition and working memory. Although multiple categories of EF have been shown to improve based on aerobic exercise, the foundation of brain development relies within its ability to utilize all three areas of EF simultaneously. Therefore, the purpose of this study was to determine the effects of exercise intensity and type of exercise (cognitive activation) on EF in elementary-aged children. **Design:** Eighteen children (mean age=10.4, SD=0.5, 61.1% girls) participated in a within-subjects experimental design consisting of four randomly selected testing days comparing exercise intensity (moderate vs. high) and exercise type (aerobic vs. cognitively activated). **Methods:** Executive functions (inhibitory control, working memory, cognitive flexibility) were measured once at baseline and following each 20-min exercise duration. Repeated measures ANOVA were used to determine significant findings between the exercise intensity and type on EF assessments (Stroop, Corsi, Berg). **Results:** The cognitively activated exercise (CAE) during moderate intensity exhibited greater cognitive flexibility scores among each intervention, while significant improvements were made when compared to moderate aerobic exercise. Scores within inhibitory control and working memory saw an overall improvement beneficial to aerobic exercise only. Contrary to the hypothesis, there was a significant negative effect of the CAE at vigorous intensities within certain variables of inhibitory control. **Conclusion**: These findings suggest that perhaps a more complex relationship is occurring among the three core categories of EF. Outside stimuli and stressors may have both negative and positive influences on EF assessments depending on participants prior level of PA experience as well as other factors. These mechanisms are discussed in the light of theories surrounding brain derived neurotropic factor and how a stressful environment and psychosocial variables influence the relationship of EF components.

KEYWORDS: Executive Function; Exercise Intensity; Aerobic Exercise; Cognitively Activated Exercise; Inhibitory Control; Working Memory; Cognitive Flexibility

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P.S.P.

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CHAPTER I: INTRODUCTION

The effects of physical activity on brain development in adults have been thoroughly studied in recent years, slowly transitioning to children populations (ages 5–17 years), with evidence supporting the positive correlation between exercise and cognitive function for both age groups (Chang et al., 2012; Diamond & Ling, 2016; Hillman et al., 2009). Previous studies examining children samples, primarily focus on the FITT principles (frequency, intensity, time, type) and their effects on executive function (EF). Specific FITT principles have been researched more in-depth than others, including the dose-response relationship of frequency and time, as well as the differences of intensity levels within physical activity (Davis et al., 2011; Tomporowski et al., 2008; Hillman & Buck, 2009). While these child studies have provided the foundation for what is known about the influences of exercise on EF, there are still important variables to consider that have not been researched in detail.

EF is a set of processes that involves managing oneself and one's resources in order to achieve a goal (Burgess & Simons, 2005). It is an umbrella term for the neurological skills involving mental control and self-regulation (Banich, 2009). These skills are the mental processes that enable us to plan, focus attention, remember instructions, and juggle multiple tasks successfully (Chan, et al., 2008). Most life tasks require a successful alignment of several types of executive functioning skills. Through current research, three dimensions of these functions are highlighted: working memory, inhibitory control, and cognitive flexibility (Anderson & Levy, 2009; Theeuwes, 2010). In the school setting, teachers identify the most relevant problems as those pertaining to EF skills (Rimm-Kaufman et al., 2000). For instance, paying attention, managing emotions, and communication are more important than knowing their numbers and letters, at least in the early years of education (Lewitt & Baker, 1995). Furthermore, EF skills are referred to by many experts as the biological foundation for school readiness (Barkley, 2001; Bierman et al., 2008). Research also supports that children with stronger working memory, inhibitory control, and cognitive flexibility have been shown to have significantly higher test scores in literacy and mathematics (Blair & Razza, 2007; Fuchs et al., 2005; Greenberg et al., 2007; McClelland et al., 2007).

In previous literature, most of the effects of physical activity regarding EF have been assessed on a dose-response and intensity level relationship (Davis et al., 2011; Mcmorris et al., 2016; Chang et al., 2013). In more current, yet limited research, Moreau et al. (2019) used high intensity training (HIT) to show improvements in working memory and inhibitory control (focus) in children. Continuing the trend, multiple studies found that exercise at moderate to high intensity levels improved results in both the Stroop Task (inhibitory control) and Digit Span Task (working memory) (Van Der Niet et al., 2016; Chang et al., 2013). Although cognitive flexibility showed no improvements in the preceding studies, researchers indicate that this variable may be more associated with exercise type rather than intensity (Pesce et al., 2009; Schmidt et al., 2015). Previous studies have limited exercise intensity to aerobic activities and have not included a cognitive activation component through exercise type.

While previous research has concluded that certain FITT principles enhance EF, there is limited research on how the specific type of exercise, in combination with intensity level, influences children's executive functioning skills. Although multiple categories of EF have been shown to improve based on aerobic exercise, the foundation of brain development relies within its ability to utilize all three areas of EF simultaneously. Therefore, the purpose of this study was to determine the effects of exercise intensity and type of exercise (cognitive activation) on EF in elementary-aged children.

CHAPTER II: METHODS

Sampling Overview

The target population of this study was generalized to upper elementary school-aged children. A total of 18 typically developing children (11 girls and 7 boys) aged 10-11 years participated in the study. These children were recruited from a local elementary school in central Illinois. Students were randomized into one of the two cohort groups, depending on the days they were in school. Once the sample had been selected, the researcher obtained school and district level consent, following the school district's research protocol. Additionally, all procedures were in accordance with and approved by the Illinois State University's institution review board. Two subjects did not complete all five days of the intervention and were therefore not included in statistical analysis for those tests.

Study Design and Protocol

A crossover (within-subjects) experimental design was used, consisting of five total data collection dates for each cohort. One of these days was used to collect descriptive statistics and baseline measures at rest for each subject (Table 1). On days of intervention, participants completed a 25-minute bout of exercise including a 3-minute warmup, 2-minute cooldown, and 20 minutes of moderate or vigorous activity. Students spent, at minimum, a total of 15 minutes in the designated heart-rate zone prior to EF assessments. The following intensity levels measured for each day of assessment were moderate-level intensity (MLI) and vigorous-level intensity (VLI) measured via heartrate using the Polar H10 Heart Rate Sensor with chest strap (Polar Electro Inc., Lake Success, NY). Trials were randomized according to exercise type and intensity. Participants served as their own control, paired alongside with the intensity of aerobic exercise. Before collecting data, both groups had instructional information and demonstrations on how to properly wear and activate their Polar Sensor. Prior to baseline EF tests, subjects were taught, and able to practice, each assessment type. The Stroop, Digit Span, and Berg Card Sorting Test (BCST) were used in order to assess EF in the following sub-categories; cognitive inhibition, working memory, and cognitive flexibility, respectively. All assessments were administered immediately following exercise in a randomized order. Data was automatically stored to a password protected flash drive following each day of intervention. The researcher then de-identified all data prior to saving scores onto an Excel spreadsheet using Windows 10.

Exercise Variables

Exercise intensity. As previously indicated, intensity levels included MLI and VLI. Intensity levels were determined based on percentages (MLI = 60–75%; VLI = 76–90%) of subjects' age-predicted maximal heart rates (APMHR) (Tanaka et al., 2001). These measures were then inputted into the Polar system for each subject and utilized during testing. Participants were given instructions and motivation to stay within their heart rate (HR) ranges for all four days of testing. These ranges included: baseline/resting (HR 54–119bpm), MLI (HR = 120–149bpm), and VLI (HR = 150–200bpm) (Riebe et al., 2018). Aerobic exercise intensities (AE) served as a control in this experiment and were then used for comparison during baseline and executive functioning assessments. Intensity levels paired with cognitively activated exercise (CAE) will be compared to the controlled AE as well as between intensity levels of the CAE.

Exercise type. Exercise type was categorized as AE and CAE. AE served as the primary control in this study, while CAE served as the primary treatment. The 20-meter FitnessGram Pacer Test was used for all AE intervention. Level 3 of the Pacer Test was used as a constant because of the increased tempo of cadence, enabling participants to increase or decrease participation. Subjects could self-assess their intensity level by monitoring HR throughout the study session. The researcher also gave verbal cues when certain studies were close to falling outside of the designated HR zone. They therefore were able to stay in the appropriate HR zone by increasing or decreasing their continuous participation in the Pacer test. The CAE consisted of a researcher-developed cognitively induced individual gameplay and movement patterns. This activity included color-pattern recognition, task switching, and gameplay changes based on movement patterns. Subjects were to correctly complete each pattern (Figure 1) and then move to the next, while keeping their HR in the designated intensity range. A total of 25 patterns were arranged in a packet and randomized for each testing day. Each type of exercise took place a total of two times, paired with each exercise intensity. Exercise type was randomized for both groups during all four sessions. At baseline, participants were introduced, informed, and allowed to practice the CAE gameplay design and rules.

Executive Functioning Measures

All EF subcategories (inhibitory control, working memory, and cognitive flexibility) were assessed using validated computer programs to administer each test. The Psychology Experiment Building Language (PEBL) test battery was downloaded, by the researcher, to public school-issued devices. The PEBL test battery not only administers each of the proceeding EF assessments, but also organizes and stores data according to subjects' deidentified username (Mueller & Piper, 2014). Each assessment was randomized for both cohorts following baseline measures and all four physical activity testing sessions.

Inhibitory control assessment. Inhibitory control is the most studied subcategory of EF. This skill allows humans to reason through impulsive actions, in order to choose the best response at any given moment. It is also the core factor of EF which enables other areas of EF, such as working memory and cognitive flexibility, to process accordingly. To assess inhibitory control, the Stroop Task has most commonly been used, in not only exercise specific research, but across the board from behavioral psychology to areas of neuroscience. The Stroop Task measures inhibition by having to select correct responses for the colors of words. Subjects not only select color during congruent and incongruent trials, but also while subconsciously eliminating outside stimuli to influence selective attention (Macleod, 1991). Both response time (milliseconds) and accuracy (total error) for congruent and incongruent trials are recorded. Congruent trials are represented by a single-color shape with no outside stimulus (i.e., written word) affecting choice. On the contrary, incongruent trials are indicated by a written word, in combination with color (i.e., the word “horse” written in the color red). Regardless of the word or shape, correct responses are always indicated by the single-color of the shape or word. Intrusion error is recorded for incongruent trials and occurs when subjects choose their response based on the stimulus that is meant to cause confusion. In the Stroop Task, intrusion error is caused by the participant selecting the spelling of color option instead of the actual color of the text.

Working memory assessment. The second, and also commonly studied core EF category is working memory. Smith and Jonides (1999) defined working memory as the ability to hold and utilize information stored in the mind. The Corsi Block-Tapping Test, along with the numerous response time (RT) measurements were all developed to assess working memory separately from inhibitory control. In the Corsi Test, the participant must repeat a pattern of highlighted blocks in the same order (Alloway et al., 2009). With each correct trial, subjects lengthen the pattern until they commit two mistakes. At that time, the test is complete. Total memory span (msp) is recorded for each test. Memory span takes the minimum list length (2) , adds the total number correct (N), and divided by the number of lists at each length (2).

Cognitive flexibility assessment. The final core EF category is cognitive flexibility. This is the least studied measurement of the three subcategories and therefore is the focus of exercise type. Cognitive flexibility utilizes task switching by understanding spatial perspectives and different point of views (Garon et al., 2008). The Wisconsin Card Sorting Test (WCST) has subjects classify cards according to color, shape, or number. Rules change every ten cards sorted, therefore assessing the flexibility of subjects' cognition (Zelazo, Muller, Frye, Marcovitch, & Sutherland, 2003). While the PEBL test battery does not include the WCST, it does provide its own comparable version called the Berg Card Sorting Test (BCST) – 64, which was used to assess cognitive flexibility in this study. Variables collected for the BCST include number of correct sorts (total correct), number of incorrect sorts (regular error), and perseverative error. Perseverative error occurs after a rule change has happened. The subject is aware of this rule change but continues to sort the cards based on the previous rule. Scores for the BCST are recorded as percentages of total correct, regular error, and perseverative error.

Statistical Analysis

Descriptive statistics and anthropometry. Height and weight were measured by the researcher at the school with a digital body scale and stadiometer. Body mass index was computed by dividing the weight (in kilograms) by the square of the height (in meter). Mean and standard deviation were calculated for EF scores at baseline. The sex variable was included to distinguish differences between male and female subjects. 'Prior physical activity experience' was also included as a covariate and based on years of physical activity in extracurricular sports. If a participant had two or more years of organized sport and/or extracurricular activities, they were then considered as having prior PA experience. All analyses were conducted using IBM SPSS statistics software version 27 for Windows (IBM, Armonk, NY).

Primary and secondary outcome measures. The primary aim of this study was to determine the effects of exercise type, in combination with exercise intensity, on EF in elementary-aged children. In order to determine the significance of these effects, repeated measures analysis of variance (ANOVA) was used to compare differences of within-subjects' assessments at baseline to each posttest assessment including intensity and exercise type. A total of 9 ANOVAs were performed for variables related to executive functioning. Analyses of covariance (ANCOVA) were used to test group differences on executive function measures at posttest among categorical covariates (sex, BMI, prior physical activity experience). There were two between-subject independent variables with two levels (sex categories: male and female; prior physical activity experience categories: more than two years, less than two years) and one between-subject independent variable with three levels (BMI categories: normal weight, overweight, and obese) (Cole & Lobstein, 2012). Level of significance was set at 5% ($\alpha = .05$).

CHAPTER III: RESULTS

Descriptive Statistics for both boys (n = 7) and girls (n = 11) are presented in Table 1 as means/standard deviation. From the total sample (n =18), the average age of participants was 10.4 years with a resting heart rate of 74.0 beats per minute. A mean BMI of 21.4 was recorded, with 27.7% of the subjects classified as normal weight (n = 5), 33.3% overweight (n = 6), and 38.9% obese (n = 7). Prior physical activity experience reported that 38.9% of students had no prior extracurricular experience, whereas 61.1% had at least 2 years of experience or more.

For each of the proceeding EF sections, a repeated measures ANOVA was used to compare mean differences of within-subjects' assessments over five levels of measurements, indicated by exercise type and intensity. These mean differences, along with standard error and confidence intervals are depicted in Tables 2–10. Each EF assessment may include more than one within-subjects' variable, and therefore will be included under the corresponding test. Covariate differences including sex, BMI, and prior PA experience were all included as 'between-subjects' factors. These comparisons are indicated by Figures 2-9. The F-values, along with P-values indicating levels of significance ($\alpha = .05$), will be reported in the text for statistically significant differences.

Stroop Task

Response time for congruent trials. Table 2 includes the results of the repeated measures ANOVA for all 5 levels of mean response time as well as standard error and confidence intervals. Results found that mean scores of response time for congruent trials were statistically significant when comparing baseline to AE-Mod ($F(4,28) = 4.24$, $p = 0.008$). This finding indicates that of the five-exercise type and intensity comparisons, only AE-Mod RT significantly improved (5013.68 ms faster, $p = 0.029$). Figure 2 shows the significant differences for the effects of BMI on RT. Normal BMI mean score was faster than the overweight group (14142.55 ms, $p = 0.009$) and obese group (10889.27 ms, $p = 0.018$). Figure 3 indicates the mean difference between prior PA experience and no prior PA experience on RT (18356.95 ms, $p < 0.001$), in favor of the prior PA experience group. Sex showed no significant effects on response time for congruent trials ($p > 0.05$).

Total error for congruent trials. Table 3 includes the results of the repeated measures ANOVA for all 5 levels of total error for congruent trails as well as standard error and confidence intervals. Results found that mean scores of total error for congruent trials were statistically significant ($F(4,28) = 14.08$, $p < 0.001$). These findings indicate that baseline errors were significantly less when compared to CAE-Vig (4.64, $p = 0.011$), CAE-Mod (4.90, $p < 0.001$), and AE-Vig (2.19, $p = 0.030$). CAE-Vig errors were higher than baseline (4.64, $p = 0.011$), AE-Vig (2.45, $p = 0.040$), and AE-Cog (3.27, $p = 0.012$). CAE-Mod errors were higher than baseline (4.90, $p < 0.001$), AE-Vig (2.71, $p = 0.003$), and AE-Mod (3.53, $p < 0.001$). AE-Vig errors were higher when compared to baseline (2.19, $p = 0.030$) but lower than CAE-Vig (2.45, $p = 0.040$) and CAE-Mod (2.71, $p = 0.003$). Lastly, AE-Mod errors were lower when compared to CAE-Vig (3.27, $p = 0.012$) and CAE-mod (3.53, $p < 0.001$). Figure 4 indicates the female group committed less errors than male (9.62, $p = 0.013$). Figure 5 indicates the normal BMI group committed more errors when compared to overweight group (9.04, $p = 0.040$) and to the obese group (7.91, $p = 0.045$). Figure 6 depicts the mean differences of prior PA experience indicating the group with prior PA experience committed less errors as compared to the group with no prior PA experience (8.99, $p = 0.018$).

Response time for incongruent trials. Table 4 includes the results of the repeated measures ANOVA for all 5 levels of RT for incongruent trials as well as standard error and confidence intervals. Results found that mean scores of response time for incongruent trials were statistically significant ($F(4,28) = 2.53$, $p = 0.063$). These findings indicate that AE-Vig RT was faster than baseline (7345.20 ms, $p = 0.014$) and CAE-Mod (6168.65 ms, $p = 0.007$). Figure 7 indicates the mean difference between prior PA experience and no prior PA experience on RT (22234.95 ms, $p = 0.026$), in favor of the prior PA experience group. Sex and BMI showed no significant effects of congruent errors ($p > 0.05$).

Total error for incongruent trials. Table 5 includes the results of the repeated measures ANOVA for all 5 levels of total error for incongruent trials as well as standard error and confidence intervals. Results found that mean scores of total error for incongruent trails were statistically significant ($F(4,28) = 10.81$, $p < 0.001$). These findings indicate that subjects committed statistically significant higher amounts of error for CAE-Vig when compared to baseline (6.55, $p = 0.005$), AE-Vig (4.56, $p = 0.001$), and AE-Mod (6.76, $p < 0.001$). Sex BMI, and prior PA experience showed no significant effects on total error for incongruent trials ($p > 0.05$).

Intrusion error for incongruent trials. Table 6 includes the results of the repeated measures ANOVA for all 5 levels of intrusion error for incongruent trials as well as standard error and confidence intervals. Results found that mean scores of intrusion error for incongruent trials were statistically significant ($F(4,28) = 14.24$, $p < 0.001$). A significantly higher amount of intrusion error was present after CAE-Vig, as compared to baseline (2.97, $p = 0.003$), CAE-Mod (2.50, $p = 0.014$), AE-Vig (2.64, $p = 0.002$), AE-Mod (3.29, $p = 0.001$). Sex BMI, and prior PA experience showed no significant effects on intrusion error for incongruent trials ($p > 0.05$).

Corsi Blocks Test

Memory span score. Table 7 includes the results of the repeated measures ANOVA for all 5 levels of memory span (msp) scores as well as standard error and confidence intervals. Results found that mean memory span scores were statistically significant ($F(4,28) = 0.69$, $p = 0.603$). This finding indicates that AE-Vig had higher scores than baseline (0.37, $p = 0.030$). No other comparisons were found to be statistically significant ($p = 0.05$). Figure 8 shows the mean difference between BMI groups for memory span scores indicating normal BMI had a lower score than the overweight group (1.13, $p = 0.038$). Figure 9 indicates the mean difference between prior PA experience and no prior PA experience memory span (1.19, $p = 0.013$), in favor of the prior PA experience group. Sex showed no significant effects of congruent errors ($p > 0.05$).

Berg Card Sorting Test

Total correct percentage. Table 8 includes the results of the repeated measures ANOVA for all 5 levels of percentage of total correct as well as standard error and confidence intervals. Results found that mean percentage of total correct were statistically significant ($F(4,28) = 2.79$, $p = 0.045$), indicating that CAE-Mod scores were significantly higher than AE-Mod (3.72%, $p < 0.001$). No other comparisons were found to be statistically significant ($p = 0.05$). Sex BMI, and prior PA experience showed no significant effects on percentage of total correct ($p > 0.05$).

Regular error percentage. Table 9 includes the results of the repeated measures ANOVA for all 5 levels of percentage of regular error as well as standard error and confidence intervals. Results found that mean percentage of regular error was statistically significant ($F(4,28) = 2.60$, $p = 0.058$), indicating that CAE-Mod scores were significantly lower than AE-Mod (2.14%, $p = 0.004$). No other comparisons were found to be statistically significant ($p =$

0.05). Sex BMI, and prior PA experience showed no significant effects on percentage of regular error ($p > 0.05$).

Perseverative error percentage. Table 10 includes the results of the repeated measures ANOVA for all 5 levels of percentage of perseverative error as well as standard error and confidence intervals. Results found mean percentage of perseverative error was statistically significant ($F(4,28) = 1.55$, $p = 0.216$), indicating that CAE-Mod scores were significantly lower than AE-Mod (4.57%, $p = 0.038$). No other comparisons were found to be statistically significant ($p = 0.05$). Sex BMI, and prior PA experience showed no significant effects on percentage of perseverative error ($p > 0.05$).

Table 1. Descriptive statistics for subjects by sex

Variable	Boys (n = 7)	Girls (n = 11)	Total (n = 18)
Age (years, SD)	10.3 (0.5)	10.5 (0.5)	10.4 (0.5)
BMI (kg/m^2, SD)	20.8 (1.7)	21.8 (4.6)	21.4 (3.7)
Resting Heart Rate (bpm, SD)	72.0 (10.4)	75.8 (11.8)	74.0 (11.1)
BMI Category (%)			
Normal Weight (n = 5)	14.2%	36.4%	27.7%
Overweight (n = 6)	57.1%	18.2%	33.3%
Obese (n = 7)	28.6%	45.5%	38.9%
Prior PA Experience (%)			
No Experience (n = 7)	14.2%	54.5%	38.9%
Experienced (n = 11)	85.7%	45.5%	61.1%

Note: Data presented as means/standard deviation and percentages.
SD = Standard deviation
bpm = beats per minute
BMI = Body mass index. Normal weight BMI includes underweight.
PA = Physical activity

Table 2: Mean comparisons for the Stroop congruent response times (ms)

RTCon	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Baseline	44808.3[a]	2217.6	39564.7	50052.0
CAE - Vig	40034.7	1878.0	35593.8	44475.6
CAE - Mod	38270.3	2174.0	33129.7	43410.8
AE - Vig	39631.3	2629.8	33412.9	45849.7
AE - Mod	39794.6[a]	880.8	37711.8	41877.5

[a]. The mean difference is significant at the .05 level
Baseline = Baseline measurements
CAE - Vig = Cognitively activated exercise - vigorous intensity
CAE - Mod = Cognitively activated exercise - moderate intensity
AE - Vig = Aerobic exercise - vigorous intensity
AE - Mod = Aerobic exercise - moderate intensity

Table 3: Mean comparisons for the Stroop congruent total error

TotErrorCon	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Baseline	6.3[a,b,c]	1.8	2.1	10.6
CAE - Vig	11.0[a,d,e]	1.6	7.3	14.7
CAE - Mod	11.2[b,f,g]	1.5	7.6	14.9
AE - Vig	8.5[c,d,f]	1.2	5.6	11.4
AE - Mod	7.7[e,g]	1.3	4.7	10.7

[a,b,c,d,e,f,g]. The mean difference is significant at the .05 level

Baseline = Baseline measurements

CAE - Vig = Cognitively activated exercise - vigorous intensity

CAE - Mod = Cognitively activated exercise - moderate intensity

AE - Vig = Aerobic exercise - vigorous intensity

AE - Mod = Aerobic exercise - moderate intensity

Table 4: Mean comparisons for the Stroop incongruent response times (ms)

RTIncon	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Baseline	50601.3[a]	4963.7	38864.1	62338.4
CAE - Vig	46128.7	5459.9	33218.2	59039.2
CAE - Mod	49424.7[b]	3635.7	40827.7	58021.7
AE - Vig	43256.1[a,b]	3360.2	35310.6	51201.6
AE - Mod	44230.9	3522.9	35900.7	52561.2

[a,b]. The mean difference is significant at the .05 level
Baseline = Baseline measurements
CAE - Vig = Cognitively activated exercise - vigorous intensity
CAE - Mod = Cognitively activated exercise - moderate intensity
AE - Vig = Aerobic exercise - vigorous intensity
AE - Mod = Aerobic exercise - moderate intensity

Table 5: Mean comparisons for the Stroop incongruent total error

TotErrorIncon	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Baseline	4.1[a]	2.5	-1.9	10.2
CAE - Vig	10.7[a,b,c]	1.3	7.6	13.7
CAE - Mod	6.1	3.7	-2.6	14.8
AE - Vig	6.1[b]	0.5	4.9	7.4
AE - Mod	3.9[c]	2.0	-0.7	8.6

[a,b,c]. The mean difference is significant at the .05 level

Baseline = Baseline measurements

CAE - Vig = Cognitively activated exercise - vigorous intensity

CAE - Mod = Cognitively activated exercise - moderate intensity

AE - Vig = Aerobic exercise - vigorous intensity

AE - Mod = Aerobic exercise - moderate intensity

Table 6: Mean comparisons for the Stroop intrusion error

Intrusion	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Baseline	1.5[a]	0.8	-0.3	3.3
CAE - Vig	4.5[a,b,c,d]	0.7	2.9	6.0
CAE - Mod	2.0[b]	1.2	-0.9	4.8
AE - Vig	1.8[c]	0.3	1.2	2.5
AE - Mod	1.2[d]	0.7	-0.5	2.8

[a,b,c,d]. The mean difference is significant at the .05 level

Baseline = Baseline measurements

CAE - Vig = Cognitively activated exercise - vigorous intensity

CAE - Mod = Cognitively activated exercise - moderate intensity

AE - Vig = Aerobic exercise - vigorous intensity

AE - Mod = Aerobic exercise - moderate intensity

Table 7: Mean comparisons for the Corsi memory span

MSP	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Baseline	4.6[a]	0.1	4.3	4.9
CAE - Vig	4.9	0.3	4.4	5.6
CAE - Mod	4.6	0.3	3.9	5.4
AE - Vig	5.0[a]	0.1	4.8	5.2
AE - Mod	4.8	0.2	4.3	5.4

[a.] The mean difference is significant at the .05 level
Baseline = Baseline measurements
CAE - Vig = Cognitively activated exercise - vigorous intensity
CAE - Mod = Cognitively activated exercise - moderate intensity
AE - Vig = Aerobic exercise - vigorous intensity
AE - Mod = Aerobic exercise - moderate intensity

Table 8: Mean comparisons for the Berg total correct percentage

TotCorr	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Baseline	83.4	1.2	80.6	86.2
CAE - Vig	83.6	1.1	81.0	86.3
CAE - Mod	85.6[a]	1.2	82.7	88.5
AE - Vig	83.8	1.1	81.3	86.4
AE - Mod	81.9[a]	1.5	78.5	85.4

[a]. The mean difference is significant at the .05 level

Baseline = Baseline measurements

CAE - Vig = Cognitively activated exercise - vigorous intensity

CAE - Mod = Cognitively activated exercise - moderate intensity

AE - Vig = Aerobic exercise - vigorous intensity

AE - Mod = Aerobic exercise - moderate intensity

Table 9: Mean comparisons for the Berg regular error percentage

RegError	Mean	Std. Error	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Baseline	5.4	1.0	3.1	7.7
CAE - Vig	5.6	0.7	4.0	7.3
CAE - Mod	4.5[a]	0.6	3.2	5.8
AE - Vig	4.9	0.4	3.9	6.0
AE - Mod	6.6[a]	0.9	4.6	8.7

[a]. The mean difference is significant at the .05 level
Baseline = Baseline measurements
CAE - Vig = Cognitively activated exercise - vigorous intensity
CAE - Mod = Cognitively activated exercise - moderate intensity
AE - Vig = Aerobic exercise - vigorous intensity
AE - Mod = Aerobic exercise - moderate intensity

Table 10: Mean comparisons for the Berg perseverative error percentage

PersError	Mean	Std. Error	95% Confidence Interval	
			Lower Bound	Upper Bound
Baseline	33.9	1.2	30.9	36.8
CAE - Vig	32.3	1.0	30.0	34.5
CAE - Mod	30.4[a]	3.2	22.8	38.1
AE - Vig	36.6	3.5	28.4	44.8
AE - Mod	35.0[a]	3.3	27.2	42.8

[a]. The mean difference is significant at the .05 level
Baseline = Baseline measurements
CAE - Vig = Cognitively activated exercise - vigorous intensity
CAE - Mod = Cognitively activated exercise - moderate intensity
AE - Vig = Aerobic exercise - vigorous intensity
AE - Mod = Aerobic exercise - moderate intensity

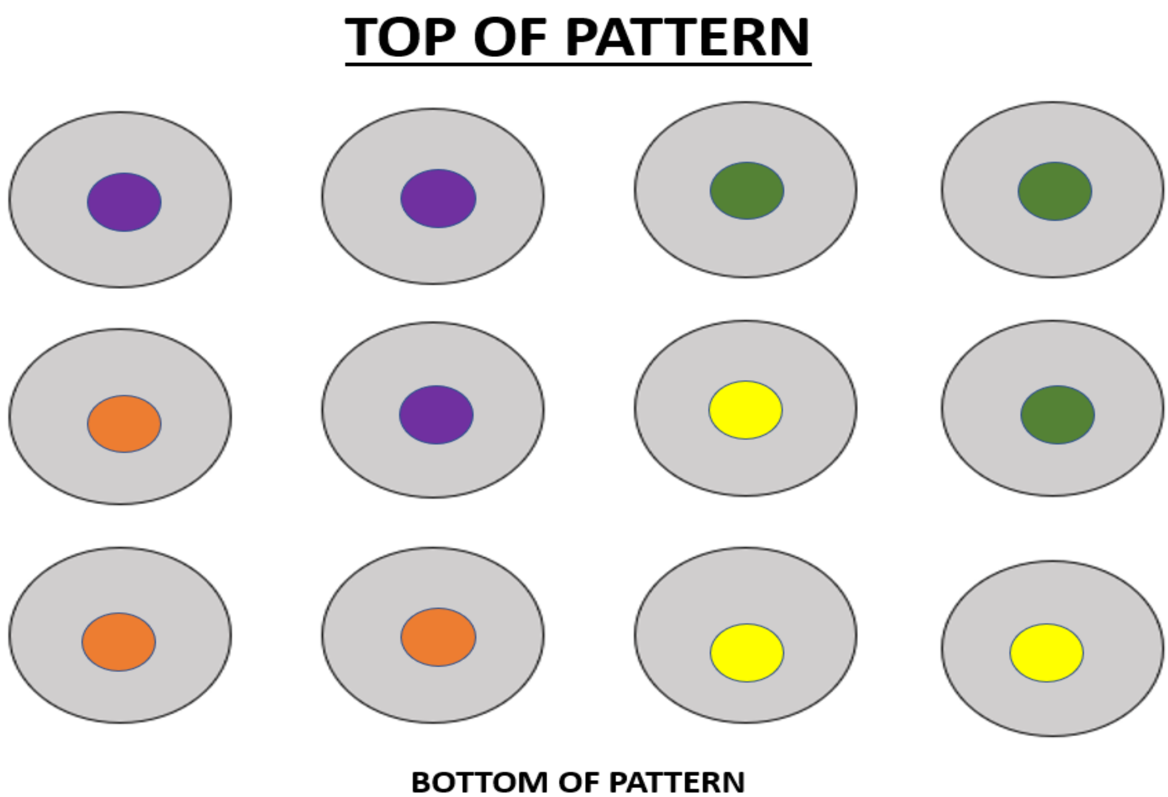

Figure 1. Example of a dot pattern from the cognitively activated exercise activity.

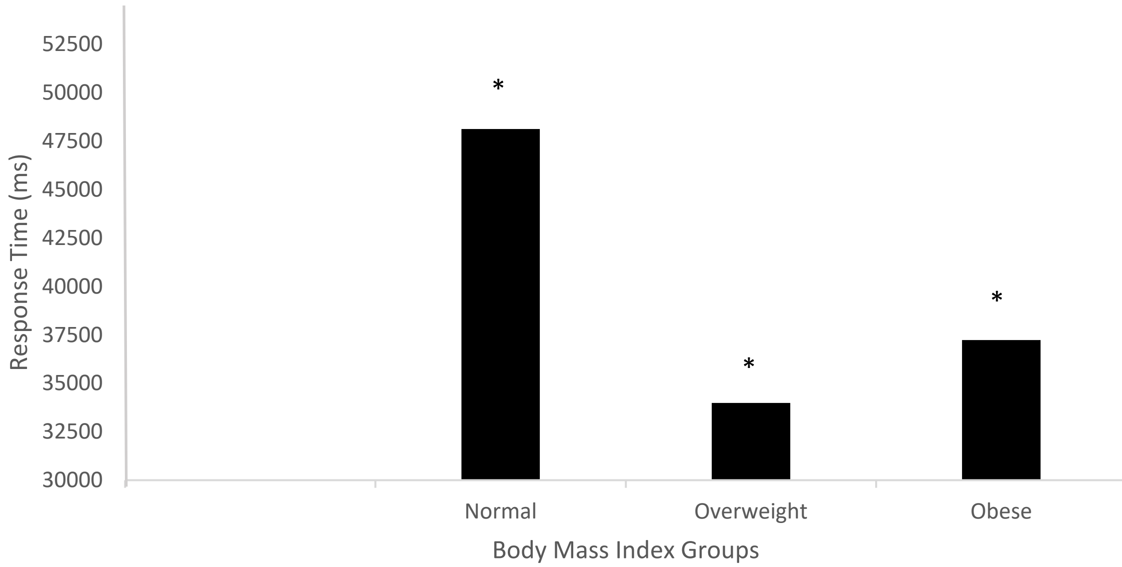

Figure 2. Effects of body mass index on response time for congruent trials of the Stroop Task. (n = 16) Note. *$p < 0.05$.

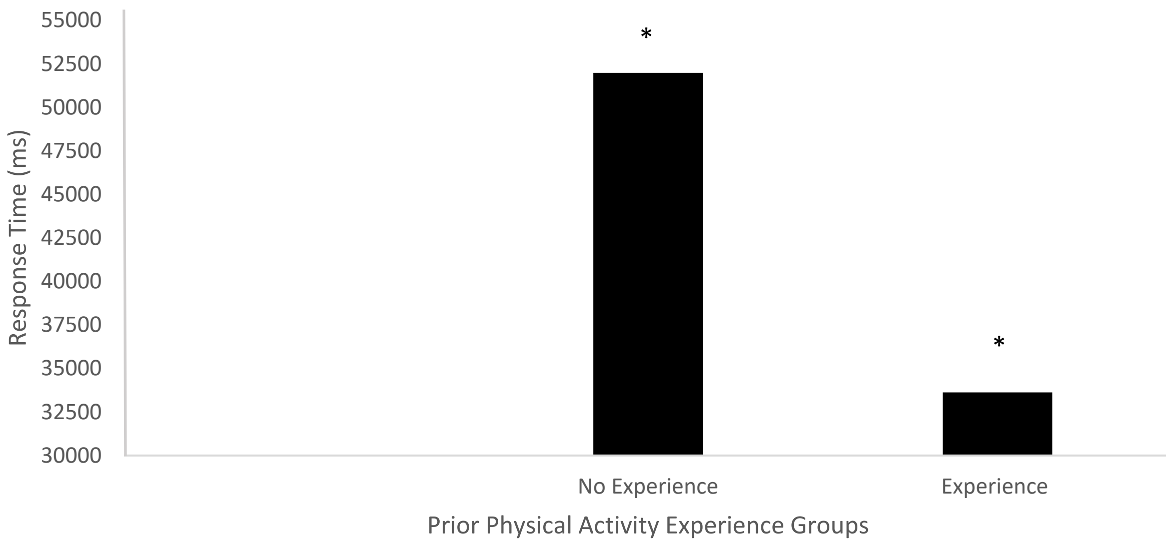

Figure 3. Effects of prior physical activity experience on response time for the Stroop Task. (n = 16) Note. *p <0.05.

Figure 4. Effects of sex on total error for congruent trials of the Stroop Task. (n = 16) Note.

*p <0.05.

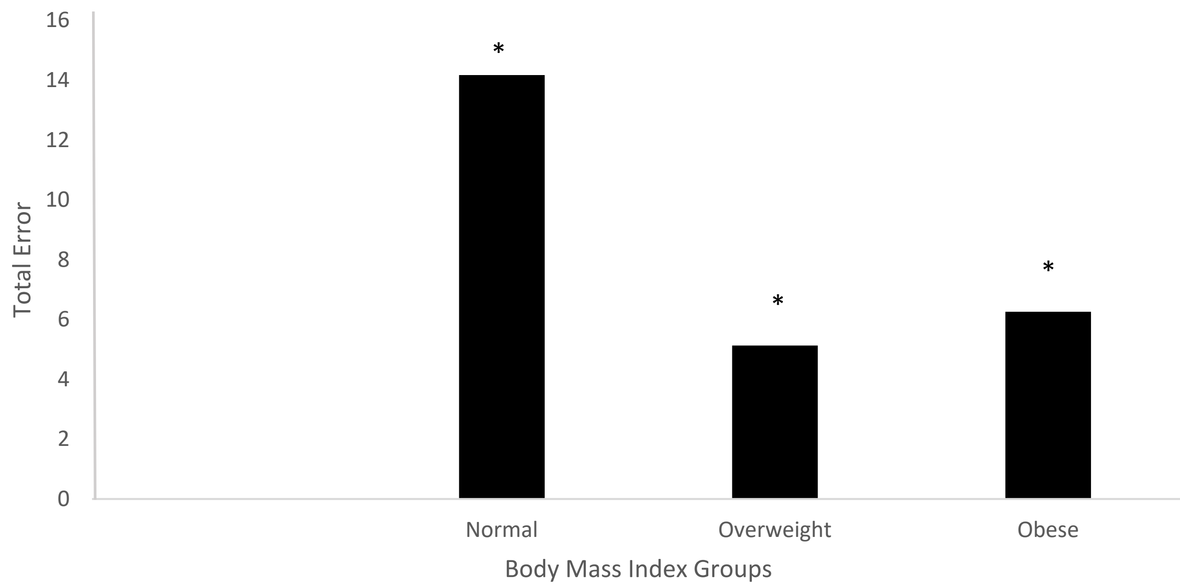

Figure 5. Effects of body mass index on total error for congruent trials of the Stroop Task. (n = 16) Note. *p <0.05.

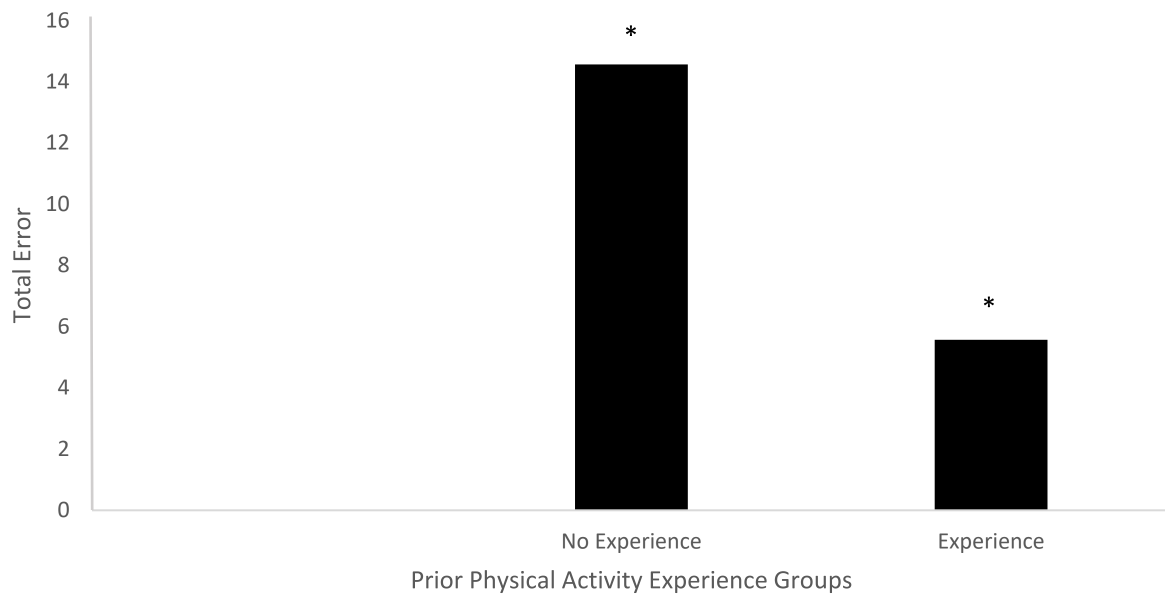

Figure 6. Effects of prior physical activity experience on total error for the Stroop Task. (n = 16) Note. *p <0.05.

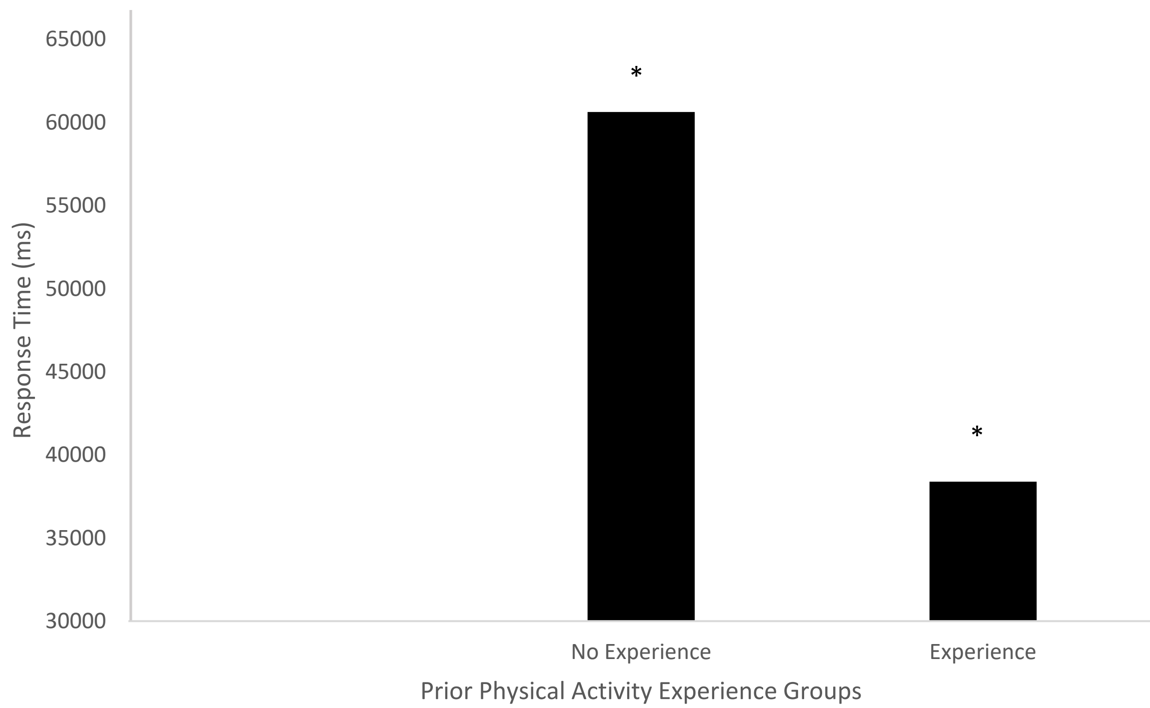

Figure 7. Effects of prior physical activity experience on response time for incongruent trials of the Stroop Task. (n = 16) Note. *p <0.05.

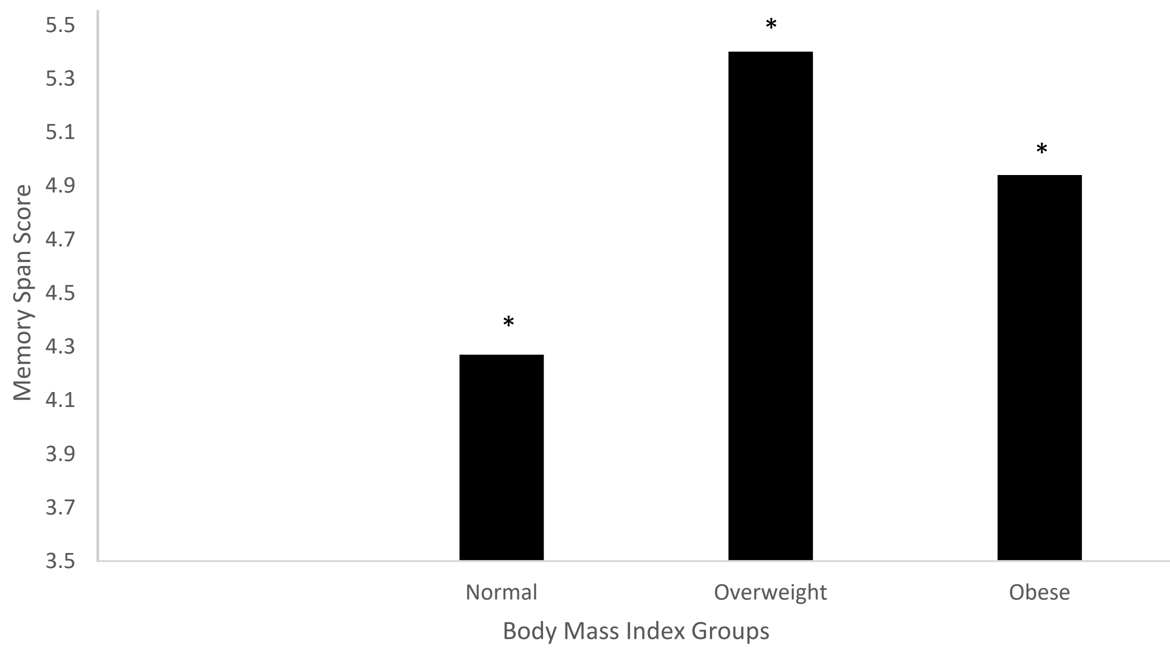

Figure 8. Effects of body mass index on memory span for the Corsi Block Task. (n = 16) Note. *p <0.05.

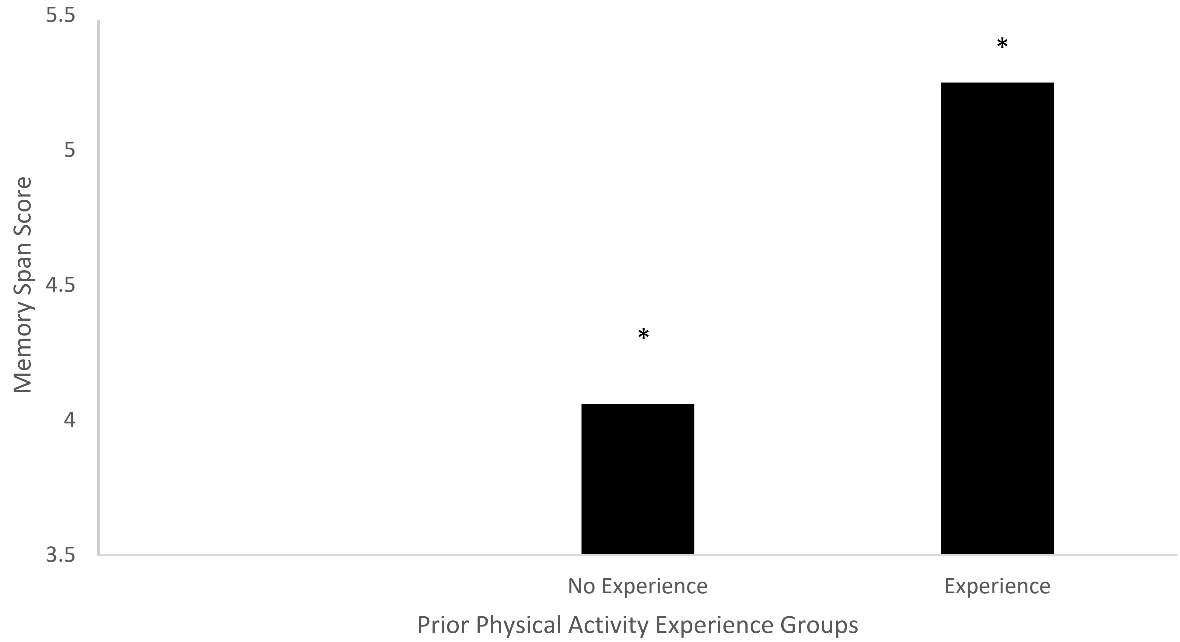

Figure 9. Effects of prior physical activity experience on memory span for the Corsi Block Task. (n = 16) Note. *p <0.05.

CHAPTER IV: DISCUSSION

The aim of this study was to investigate the effects of exercise type and intensity on three main EF assessments' key variables on elementary-aged children. It was hypothesized that exercise type, in combination with intensity levels, would improve all three core categories of EF. Likewise, researchers believed a statistical significance would be found in cognitive flexibility (BCST) in favor of the CAE trials. In summary, the results showed AE was more beneficial to both inhibitory control and working memory than CAE. Even more surprising was the finding that CAE, in combination with a vigorous intensity inhibited the previously mentioned areas of EF. However, in comparing variables for cognitive flexibility, the CAE-Mod intervention indicated improvements over AE-Mod in all three sub variables.

Covariate analysis including sex, BMI, and prior PA experience, indicate significant differences were observed during the Stroop Task and Corsi Test. However, no covariate differences were found during the BCST. While results support previous findings demonstrating that exercise intensity improves EF in children (Diamond & Ling, 2016; Ellemberg & St-Louis-Deschênes, 2010; Pontifex & Saliba, 2013) and that exercise modalities influence cognitive flexibility (Pesce et al., 2009; Schmidt et al., 2015; Ziereis & Jansen, 2015), there needs to be clarification on the specificity of both factors regarding the corresponding categories of EF. These findings suggest that perhaps certain mechanisms and physiological adaptations are occurring at different capacities depending on the combination of exercise intensity with a cognitively activated game, and therefore need to be discussed.

Stroop Task Measuring Inhibitory Control

Previous literature has shown that aerobic exercise positively influences RT scores and total error during Stroop assessments (Buck, et al., 2008; Chen et al., 2014; Hillman et al., 2009).

However, the congruent RT and congruent total error comparisons determined baseline measures to be the lowest overall in both variables. This could in fact be due to one of two, or both reasons outlined in the following. 1) Due to Coronavirus mandates and school closings, research collection was pushed back into December and January. Weather conditions were not always favorable, but the PA portion of this intervention was done outdoors in winter temperatures. These temperatures and added environment stressors may have influenced inhibitory control assessment scores based on a stress hormone response on brain derived neurotropic factor (BDNF) production. BDNF will be explained in the proceeding text. 2) Diamond and Ling (2018) agree that aerobic exercise has been shown to improve cognitive function and EF, however, of an included 181 studies looking directly at exercise type and EF only 41% of these articles even suggest evidence of EF benefits. This research specifically outlines other 'mindful' types of physical activity that increase the percentage of suggestive and clear evidence for EF benefits. Their study is in no way disregarding the benefits of aerobic exercise, it is solely suggesting that other factors may play a role in the activation of inhibitory control.

Incongruent RT scores align with Best (2010), in that AE-Vig increases the reaction of subjects' selection. During each assessment the order of congruent and then incongruent testing was consistent with congruent trials taking place first. While all EF assessments were randomized, the PEBL program does not allow to change the congruent/incongruent order in the Stroop Task. Therefore, the AE-Vig improvements on incongruent trails were always done after the congruent giving the subjects time to focus in on rules and order. The most surprising discovery, going against the researchers' hypothesis was that total error in incongruent trails and intrusion error significantly increased with CAE-Vig.

This discovery can possibly be explained through understanding the relationship of BDNF and cortisol. BDNF is a protein that strengthens neural connectivity and plays a relevant role in angiogenesis. During childhood while the prefrontal cortex (CPF) is still maturing, there is a sharp increase in brain plasticity (Cotman, et al., 2007; Galvan, 2014). While the connection of BDNF and physical activity in children is still in its infancy, animal, adolescent, and adult studies have shown the positive increase of BDNF due to exercise (Christakis, et al., 2012; de Azevedo, et al., 2019; Jeon & Ha, 2017). Cortisol or corticosterone (animal studies), is released in response to stimuli such as psychological oppression, anxiety, fear, and stress (Jeon & Ha, 2017). These cortisol producing events in turn induce changes in BDNF, which ultimately decreases BDNF expression (Russo-Neustadt, et al., 2001; Ke, et al., 2011). Therefore, added psychosocial 'stress', potentially caused by the cognitively activated exercise, paired with elevated exercise intensity (CAE-Vig), could be inhibiting the positive effects of BDNF on inhibitory control.

Corsi Block Test Measuring Working Memory

Similar to the results of inhibitory control, working memory showed significant improvements for the AE-Vig trials compared to baseline. This follows the trend of current research from Van Der Niet et al. (2016) and Chang et al. (2013). Again, looking at the effects of overstimulation and BDNF, the cognitively activated exercise trials included a working memory component. Subjects were required to remember or memorize the order and location of colors for each pattern. While the literature is confident that both inhibitory control and working memory work in unison and develop in children from the ages of 6-10 years, this period of late childhood could also be most vulnerable to environment factors (Jurado & Rosselli, 2007; Kamijo et al., 2011). For this reason, perhaps the inclusion of such a cognitively demanding game limited the participants scores during CAE. There could also be a 'burnout' factor that after 20 minutes of moderate -vigorous exercise, paired with the cognitive task, participants had lost focus and therefore interest in the Corsi Task. Both reasons relate back to the effects of cortisol on BDNF.

Diamond and Lee (2011) indicate that poor EF scores in students are related to 'burnout' on many levels. Wang et al. (2018), although using the adult population, found that cortisol levels increase during aerobic exercise. Therefore, if the exercise alone is already increasing cortisol, maybe the increased overstimulation from the CAE pushes the working memory components overboard and in turn limits the positive effects.

Berg Card Sorting Test Measuring Cognitive Flexibility

In each of the three BCST variables, CAE-Mod mean scores were highest and statically significant higher when compared to AE-Mod. These results support the researchers' hypothesis in that CAE significantly improves cognitive flexibility scores when compared to AE. An array of studies has shown the positive correlation for multiple types of exercise (aerobic, yoga, martial arts, open-skills, and team sports) on cognitive flexibility (Egger & Schmidt, 2018; Schmidt, et al., 2015; Tomporowski, et al., 2008). Likewise, Hung et al. (2018) specifically discovered higher levels of serum BDNF during open-skill exercises providing a stronger connection to BDNF and EF. The improvements of total percentage correct, regular error percentage, and perseverative error percentage may be due to the design of the CAE. In the current study, the CAE game was designed to include aspects of each EF category, specifically cognitive flexibility. The task-switching component of the game took place by a change in multiple rules throughout the 20-minute duration.

These changes were done to activate cognitive flexibility. Results indicate that this game design was successful at improving cognitive flexibility within the study. Although CAE-Mod trumped AE-Mod, the level of intensity during CAE was not relevant to these findings. Explanations and findings, once again, point to the elevated stimuli during gameplay. Again, it could be that during moderate PA, subjects were able to regulate their attention to the task at hand while BDNF levels increased. However, once the intensity entered the vigorous category, the BDNF levels rose too high and then impaired the assessment scores for CAE-VIG.

Overall Outcomes with Secondary Measures

Overall outcomes. Due to the complexity of EF and each of its subcategories, overlap between these findings need to be explained. Processes within EF including updating and monitoring involve different subcategories such as working memory and inhibition. Likewise, switching requires disengagement of processing operations (inhibition) and irrelevant tasks in order to perform operations involved in the immediate task (Miyake & Shah, 1999). Therefore, just as the three core components work together for certain functioning purposes, they may also inhibit the other(s) as well. When core elements of EF are not completely developed or there are unknown stimuli, children and adults may shift focus to the main EF component needed (Best, 2010; Diamond, 2013). Also, the maturation of certain cortical areas in children has been linked to the development of processing speed (Casey et al., 1997).

In the current study, results indicate that the AE-Vig trials were more successful than CAE-Vig and CAE-Mod during assessments on the Stroop Task and Corsi Test. While these tests were developed to single-out each core component of EF, there may be outside factors that influence scores, especially with continuingly developing brains. The overstimulation from the cognitively activated exercise may have inhibited the effective functioning for inhibition and working memory. This is supported from the increased CAE-Mod scores for the BCST. The focus of participants attention on the cognitive task could have taken away attention from the other components within EF. Similarly, the effects of stress, brought on from a plethora of reasons inhibiting BDNF, may also explain the significant decrease in CAE-Vig trials.

Covariate outcomes. Sex, BMI, and prior PA experience were all analyzed as between-subject covariates for each of the nine EF variables. Congruent trials of the Stroop Task found that male subjects committed significantly higher levels of total error. Davis et al. (2011) found similar results in the child population although not specific to total errors. Both planning and attention scores (inhibitory control and working memory) were lower in boys than in girls. Adult populations also point to an advantage in females scores relating to the crossover of inhibitory control and reading (Baroun, & Alansari, 2006; Mekarski, 1996). No other sub-category found the sex covariate to be a significant factor in positive or negative scoring. Even with large indications that female subjects typically outperform male subjects in certain areas of cognitive abilities, this may be due to factors outside of EF (Baroun & Alansari, 2006; Wei et al., 2012).

Prior PA experience occurred to be significant on three Stroop variables (response time congruent, total error congruent, and response time incongruent) and for the memory span of the Corsi Test. In previous studies, Jacobson et al. (2014) found that in the adult population, both inhibition and problem-solving skill increased between athletes and non-athletes. Ishihara et al. (2018) and Ishihara & Mizuno (2018) found comparable results resembling the population of the current study. Not only did participants score higher on both inhibitory control and working memory variables within each study, enjoyment and competence increased due to this prior experience. Although the previous results were aligned with a specific sport or athlete population, these studies shed light onto the cognitive component of physical activity and how having prior experience may benefit certain components of executive function.

Previous studies have indicated the positive effects for multiple types of physical activity on EF assessments and BMI. Although not all core components saw improvements within each study, it can be concluded that inhibitory control and working memory reap the most benefits (Davis et al., 2007; Davis et al., 2011; Crova et al., 2014). In the current study, results show a similar trend for BMI. Both memory span and congruent total error showed significant differences of scores in favor of the overweight and obese BMI group. This could have been due to the vigorous intensity level during aerobic exercise. Davis et al. (2007) found that high intensity aerobic exercise impacts the overweight and obese populations more than normal weight individuals. While Hillman et al. (2009) and Hillman et al. (2005) have shown that current high fitness levels are indicators of higher EF scores, specifically with the Stroop Task, the ceiling for improvement is much higher for the overweight and obese populations. Crova et al. (2014) solidified that overweight children had more pronounced pre- to post-intervention improvements in inhibition than lean children only if involved in enhanced physical education. Therefore, the results from the current study agree with Davis' and Crova's research in terms of total error and memory span.

CHAPTER V: STRENGTHS AND LIMITATIONS

This study does have its limitations, starting with the design. Firstly, a total sample size of 18 (11 girls and 7 boys) subjects were less than the required amount for this type of study. Even with the small sample size, EF assessments could have been limited to one core category per testing date. Originally, around 100 5th grade students planned to take part in data collection, however, due to the Coronavirus pandemic there was a limited amount of in-person availability of subjects, time, and resources for data collection. Secondly, the field-based environmental conditions were not optimal for consistency and participant enjoyment. Ideally, all testing days would have been indoors where weather may not have played a factor. Again, due to the limited space and requirements within the school district during this time fluctuating weather conditions had to be used for the vigorous testing days.

In contrast, positive takeaways from this study include the inclusion of the variable 'prior PA experience'. As indicated from the discussion section, mechanisms influenced by this type of 'practiced' development can influence stress related to more positive or negative EF outcomes. Another strength of the study was randomization for the intervention groups per day and randomization of EF assessments. Assessment order was randomly selected prior to intervention and then completed on that same day. A third strength of this study was the use of heart rate to determine intensity levels. While this has been done in most lab type experiments focusing on aerobic exercise, it is a variable that is typically not presented during field-based research based on exercise type.

Lastly, an important characteristic of this study to note was the development and implementation of the cognitively designed exercise game. This variable could potentially be both a strength and limitation for obvious reasons. The first is that no prior validity and/or reliability assessments were done on this game design to validate if it accurately measures EF variables. Although it was specifically designed to focus on inhibitory control, working memory, and cognitive flexibility, no evidence to support this theory could have been provided. On the other hand, perhaps more physically adopted cognitive games need to be considered in future research studying exercise intensity, type, and EF.

Most studies previously listed include open skill, team games, and mindfulness activities, however, few include motivation and enjoyment as substantial factors influencing EF. This type of game design offers a 'brain-game' intertwined with physical components that could be a missing link in the connection of exercise and positive improvements on EF. Future studies should also stress the importance of prior PA experience and use more specific questionnaires to determine if subjects demonstrate differences in confidence, competence, experience, skill and enjoyment from the exercise types, no matter what type that may be. Also, if researchers are focusing specifically on BDNF and EF, measurements of stress from the environment, activity, and psychosocial elements, specifically on cortisol response would be wise to investigate.

CHAPTER VI: CONCLUSIONS

Executive functioning is set of top-down mental processes needed for attention, reacting to stimuli, goal setting, and overall cognitive function (Anderson & Levy, 2009; Theeuwes, 2010). Inhibitory control, working memory, and cognitive flexibility are frequently highlighted when discussing the most studied subcategories of EF. These three core functions do not work entirely independent from one another but, rather, they work together to produce competent executive functioning skills (Diamond, 2013; Best 2010). While previous research has proven the benefits of AE and the increased exercise intensity on inhibitory control and working memory through a depth of literature (Davis et al., 2007; Hillman et al., 2009; Hillman et al., 2015; Vazou & Smiley Oyen, 2014), the effects of CAE have been less studied on cognitive flexibility. Even fewer studies show the combination of all three core components and how they are interconnected based on sex, BMI, and prior PA experience.

The present study offers a unique glimpse at the effects of exercise intensity and type on all three EF categories. Even more interesting is how a cognitively activated game stimulates participants, having both negative and positive effects on EF assessments. Due to this stimulation, a look at BDNF and the effects of the stress hormone cortisol must be considered in future research. Although the research is still limited as far as the effects of exercise type and BDNF in the child population, these findings lead way into specific cognitive activities created to increase EF measures while observing the crossover effects between each of the three EF subcategories.

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