The effects of exercise on cognition, specifically executive function, in college-aged participants

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Introduction

From the time of the Greek philosopher Plato, exercise, and an active lifestyle, have been encouraged to promote a balanced mind and body (Erickson, 2013. The benefits of exercise most often highlighted include weight loss (and weight loss maintenance), lower blood pressure, reduced risk of cardiovascular disease, reduced risk for diabetes, and reduced risk for obesity (Hillman, C.H., Erickson, K. I., Kramer, A.F., 2008). What experts are now finding is that exercise can do more than just improve physical health, but it can also improve mental health as well. Research by Hashim et al. (2012) has shown that exercise can ward off the harmful effects of stress that can potentially contribute to the development of more serious mental diseases, like major depressive disorder and generalized anxiety disorder (p. 1017). Additionally, doctors and nurses who treat patients with depression have been long term advocates of the benefits of exercise on improving overall mood (Trueland, J., 2012, p. 25; Hopkins, M.E., Davis, F.C., Vantieghem, M.R., Whalen, P.J., and Bucci, D.J., 2012, p.60).

As the research has continued, we have begun to see a trend towards exercise warding off the effects of old age, and the senility known as dementia (Jedrziewski, M.K., Ewbank, D.C., Wang, H., and Trojanowski, J. Q., 2010, p. 448; Chang, Y., Tsai, C., Huang, C., Wang, C., and Chu, I., 2014, p. 51; Hopkins et al., 2012, p. 66). Research has shown that exercise greatly improves brain functioning through increasing cell proliferation, increasing the production of new capillary beds, changing the expression and secretion of neurotransmitters, increasing gray matter in the prefrontal cortex (indicating better myelination which translates to faster processing speeds), and improving cerebral structure and circulation (Erickson, K.I., 2013, p. 2038; Pesce, C., 2012, p. 767; Guiney, H., Lucas, S.J., Cotter, J.D., Machado, L., 2014, p. 1,5). Guiney et al. (2015) found that the relationship between exercise and cognition points towards "superior CBF (cerebral blood flow) regulation as a pathway through which regular engagement in physical activity may bring about positive changes in cognitive functioning in healthy young adults" (p.5). Before

exploring the research, we must first understand the different terms important to this project. Executive functioning, as defined by Alderman et al. (2014), is "a subset of processes associated with the selection, scheduling, and coordination of computational processes that are responsible for perception, memory, and action, and involve situations such as planning, problem solving, task switching, and inhibition" (p. 753). Additionally, Chang et al. (2014) defines executive function as "a higher-order cognitive function involved in goal-directed behavior and includes multiple aspects of cognition that are essential for daily life, including planning, inhibition, updating, scheduling, and initiation" (p.51). Cognition is, therefore, higher brain activities, which previous research has shown can be modified by exercise. Tomporowski et al. (2008) states that cognition is a "general term that reflects a number of underlying mental processes"…which include executive function, controlled processing, visuospatial processing, and speeded processing, but they noted that greatest gains after exercise were gains in executive function (p.112).

Erickson (2013) states that exercise's most profound effects can been seen through the measures of memory, processing speed, and executive function, and additionally, can potentially reduce the risk for developing cognitive dysfunction later in life (p. 2038). Hillman et al. (2008) found that there is a significant relationship between physical activity and improved cognition with both normal adults and those with the early signs of Alzheimer's disease (p.60). Jedrziewski et al. (2010) noted that animal studies have shown that mice that use running wheels had improved memory, and that learning was enhanced through exercise for older beagle dogs (p.449). Additionally, Jedrziewski et al. (2010) cites that studies have shown improved memory and executive function for control groups that participate in some type of aerobic activity (p.449). However, not all of the research points towards gains in executive functioning following exercise. Hopkins et al. (2012) notes that there needs to be a distinction between cognitive changes brought on by the arousal of the brain and changes brought on by exercise and long term improvements in cognition due to exercise (p.59). As noted by Jedrziewski et al. (2010), studies that did not show a significant statistical association between

exercise and cognition improvement did not have sample sizes larger than 1000 participants (p.448).

In terms of testing cognition, the literature has revealed that many different types of testing exist. Tomporowski et al. (2008) states that traditional IQ test, however, "provide only global measures of functioning, which may not be sensitive enough to detect subtle changes in specific aspects of cognitive functioning". Those researchers also state that "cognitive tests evaluate mental function at more molecular level of analysis than do traditional IQ tests" (p.117). Alderman et al. (2014) notes that the Stroop test is a common and accurate way to measure executive functioning (p.753). They also cited that using a reading comprehension test had been previously used to measure working memory and executive function. In their study, Alderman et al. (2014) used three cognitive performance tests: the Stroop test, the Flanker Task, and reading comprehension tests (p.754-755). The Stroop test is a way to assess information processing speed, executive abilities, selective attention, and the ability to inhibit habitual responses. The Stroop test involves a participant being presented with a word in colored text and differentiating the actual word from the color of the text the word is written in. The Flanker Task tests for interference control and involves subjects identifying between lines of "<". The reading comprehension portion involved using four SAT equivalent passages to test for working memory. The reading comprehension portion of the SAT is specifically designed to determine the person's ability to analyze, evaluate, and synthesize information. Lucas et al. (2012) also advocated for the use of the Stroop test to test cognition (p.542). Additionally, Chang et al. (2014) notes that the Stroop test has shown more pronounced results in older adults in regards to cognitive functioning (p.52). While researching the effects of cerebral blood flow, Guiney et al. (2015) utilized three different tests to measure inhibition and switching types of cognitive functioning (p.3). The three tests were labeled Pro, Anti, and Pro/Anti and involved participants reacting quickly to stimuli presented and then differentiating between the stimuli presented.

It is also important to consider the differing effects that type and duration of exercise have on cognitive tasks. Alderman et al. (2014) notes that, in order to control for the effects of arousal from exercise on cognition, cognitive testing should

take place at least 10 to 15 minutes following an exercise bout (p.753). In a research review done by Tomporowski et al. (2008), they note that the type of exercise training did not seem to matter because positive results were found following resistance training, motor skills training, physical education interventions, and aerobic training programs (p.114). In a research review done by Caterina Pesce (2012), she notes that studies do not confirm the inverted-U hypothesis, which states that "cognitive performance would improve with increasing exercise intensity and exercise-induced arousal up to an optimal point and then degrade with further arousal increments" (p.768). In actuality, "cognitive performance seems to be facilitated by lower exercise intensities immediately after exercise," and that simple treadmill running has shown benefits (p.769). Also, she states that few studies have controlled for equality in exercise intensity and duration, which this study will attempt to do. Jedrziewski et al. (2010) states that a significant association between exercise and improved cognition was only evident in exercise bouts lasting at least 20 minutes (p.452). Guiney et al. (2015) used heart rate to measure exercise intensity by keeping exercise intensity between 35% and 80% of the specific, age-predicted maximum heart rate, using the equation HR_{target}=%intensity($HR_{age\text{-}predicted\ max}$-$HR_{rest}$) + HR_{rest} (p. 4). Lucas et al. (2012) also used the heart rate values of 30% to 70% to standardize exercise (p. 542).

A thorough review of the literature indicates that there is a lack of research in one particular of the category of participants, college-aged students. This age group is particularly interesting because the brain is still developing during the college years. Research points to the fact that exercise can improve the effects of dementia and Alzheimer's disease so it is worth understanding if its effects can be seen in even younger years, potentially warding off the cognitive decline that is inevitable as people age. The benefits of exercise are well cited, and the results of this study could potentially give college students one more reason to engage in some type of physical activity.

Methodology

Participants

The current study used 20 total participants who ranged in height from 60 inches (5') to 72 inches (6'2") and ranged in weight from 110 lbs to 185 lbs (see

Table 1). The participants ranged in academic year from sophomores to seniors (see Table 3). There were five male participants and fifteen female participants (see Table 2). The subjects were recruited by word-of-mouth across the Oklahoma State University campus and classroom visits, specifically one upper and one lower division Health and Human Performance class.

Procedure

The study protocol took approximately 45 minutes for each participant. Upon arrival, the subjects filled out an informed consent waiver that explained the purpose of the study and their rights as a participant. Participants then filled out a Demographic and Current Exercise Pattern Questionnaire (Appendix A). Following completion of the questionnaire, participants read the testing directions and completed the pre-test in a quiet space. They completed a timed congruent and incongruent Stroop test on a computer (Appendices B and C). Participants were instructed to read the words aloud, always saying the color of the text and not what the text actually said. After completion of both tests, participants walked on a treadmill for 20 minutes at a self-selected speed between 3.5 and 4.0mph (typical walking speed). After completion of the exercise bout, participants sat quietly for 15 minutes to allow the effects of physiological arousal to subside. Participants were allowed to be on their phones, but instructed to remain quiet for the duration of the 15 minutes. After the rest period, participants completed a post-test of both the congruent and incongruent Stroop tests again so that pre- and post-exercise scores could be compared. To maintain confidentiality of both demographic information and Stroop Test results, all participants were assigned a number so that names cannot be associated with collected data. All participants were compensated with a $15 Amazon gift card for participation in the research study.

Descriptive Statistics (Table 1)

	N	Minimum	Maximum	Mean	Std. Deviation
Height (inches)	20	60	72	65.28	3.522
Weight (lbs)	20	110	185	143.10	23.287
Valid N (listwise)	20				

Gender (Table 2)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	5	25.0	25.0	25.0
	Female	15	75.0	75.0	100.0
	Total	20	100.0	100.0	

Year (Table 3)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Soph.	1	5.0	5.0	5.0
	Junior	11	55.0	55.0	60.0
	Senior	8	40.0	40.0	100.0
	Total	20	100.0	100.0	

Results

SPSS statistical analysis software was used to assess the data from the demographic questionnaire, as well as the pre- and post-test comparisons of the congruent and incongruent Stroop Tests. An alpha level of $p<.05$ was chosen to evaluate significance. After running a paired samples t-test, it was found that when comparing congruent pre-tests to congruent post-tests, there was not a statistically significant difference after the exercise bout ($p=.099$; see Table 4). However, upon comparison of incongruent pre-tests to incongruent post-tests, there was a statistically significant difference after the exercise bout ($p=.001$; see Table 4). Additionally, when assessing the demographic data, a non-significant positive correlation was found between GPA and physical activity level (.335; see Table 5).

Paired Samples Test (Table 4)

		Paired Differences	t	df	Sig. (2-tailed)
		95% Confidence Interval of the Difference			
		Upper			
Pair 1	Pre_cong - Post_cong	1.415516	1.735	19	.099
Pair 2	Pre_incong - Post_incong	4.021288	4.033	19	.001

Correlations (Table 5)

		GPA	PA_Level
GPA	Pearson Correlation	1	.335
	Sig. (2-tailed)		.174
	N	19	18
PA_Level	Pearson Correlation	.335	1
	Sig. (2-tailed)	.174	
	N	18	19

Discussion

After assessing the results, exercise was shown to improve cognitive functioning after a short, 20-minute bout of moderate exercise. When looking at the data from Table 4, one might conclude that because the congruent pre-tests and post-tests did not produce a statistically significant number, then exercise does not show positive effects on cognitive functioning; however, because the congruent Stroop test does not require much cognitive functioning, it is not a good measure. The better indicator of cognitive functioning is the incongruent Stroop test because it required participants to process the color of the text, not the written word (since they were different in the incongruent test). The incongruent pre-test and post-test comparisons produced statistically significant results, supporting the hypothesis that exercise can help improve cognitive functioning. Additionally, when looking at the demographic data, there is a non-significant positive correlation between GPA and physical activity level, meaning that those who have been working out for longer periods of time, have a somewhat-higher GPAs than those who have not been.

The results from this study indicate that there is a correlation between exercise and improvements in cognitive functioning, as demonstrated by the incongruent Stroop test data. The practicality of these results is that there is now some evidence to support that those who exercise before a cognitively demanding task (like a college final exam) are likely to score higher than those who do not exercise prior to the task. Now, improvements in cognitive functioning for college-aged individuals can be added to the long list of benefits that exercise provides.

Limitations

As with all studies, there were several limitations to the current study. First of all, the sample size was extremely small. With a sample size of only 20 participants, it is

difficult to generalize results. Second, the distribution of participants was not equal (neither in terms of gender nor in terms of year in school). Third, the pre-test and post-test congruent and incongruent Stroop tests were identical, which could indicate that participants scored better on the second round of tests because they had practice on the first. However, the fact that the congruent scores did not show a statistically significant improvement in times, yet the incongruent scores did, discredits this criticism of test familiarity. Fourth, most of the participants were recruited from Health and Human Performance class, and these Health Education & Promotion majors tend to be more physically active than most other college students. Finally, the lab were the study was conducted was only a semi-controlled environment, as other researchers use the lab frequently and offices are housed there. These distractions could potentially skew results.

Future Research

While this research has a few promising aspects like being one of the few to conduct this type of research on college-aged individuals, there is lots of room for improvement and future research. First of all, future research should be conducted on a larger sample size. (A sample size of 20 participants made sense for the current study, as it was an undergraduate honors thesis project.) In addition, different pre-tests and post-tests could be used to address the criticism of familiarity/practice with the tests. Finally, participants should be recruited from a variety of different academic majors and across all years in school to ensure subject pool diversity and promote better generalization with future study results.

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Appendices

Appendix A:

Demographic Information

1. Age: _____years
2. Gender: ☐Male ☐Female ☐Other
3. Height: _____feet, _____inches
4. Weight: _____pounds
5. Academic Year:

   ☐Freshman
   ☐Sophomore
   ☐Junior
   ☐Senior
   ☐Graduate Student
   ☐Other

6. What is your current cumulative OSU GPA? _____
7. Currently, how much time do you spend each week engaging in physical activity?

   _____hours

8. What is your current exercise routine?

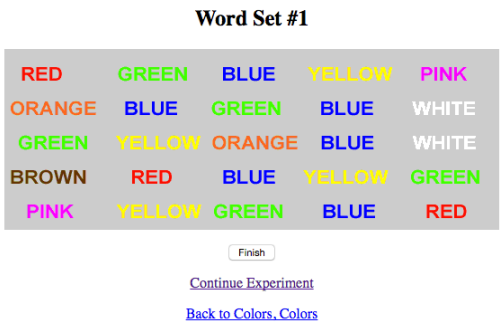
   On average, how many days per week do you exercise?
   _____days/week

   On average, how long do you usually exercise?
   _____minutes/session

9. How long have you been exercising at your current activity level (please check one)?

☐< 3 weeks ☐1-3 months ☐4-6 months ☐6-12 months ☐1-5 years ☐> 5 years

Appendix B (Congruent Stroop Test):



Appendix C (Incongruent Stroop Test):