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Impact of long-term exercise habits on cognitive test performance

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Past research has supported the idea that exercise is beneficial for the mind and cognitive functions. Further, imaging and neurotransmitter studies have shown how acute exercise can increase white matter and monoamines in the brain, thus improving cognition. On this basis, it was inferred that exercise, specifically long-term exercise, will improve an individual's cognitive performance. To determine this, college-aged subjects were assessed with baseline reaction time and simultaneous amplitude discrimination tests. They subsequently participated in an acute exercise, after completing the same tests, to examine how their performance was affected. To evaluate fitness levels, subjects took a survey reporting their fitness levels and history, and their answers were translated into a comprehensive fitness score. In analyzing fitness score with test data, results concluded that those with more robust fitness levels performed better in the amplitude discrimination task. In addition, their reaction time variability, a consistent measure of cognitive focus, decreased (i.e., *improved*) following acute exercise. In contrast, those with lower fitness levels witnessed an increase in variability following exercise. This data suggests that taking part in exercise, particularly from a young age, can have long-term beneficial effects on cognitive function.

Background

Numerous studies have stated that exercise has the ability to improve overall cognitive performance and prevent impairments that lead to diseases such as Alzheimer's and Parkinson's [1] . Additionally, exercise has been known to have positive effects on mood, motor function, learning and cognitive processing [2]. On this basis, many exercise intervention studies have been performed on aging populations [1,3], and pre-adolescent children [4], yielding results that support the belief that exercise has the ability to increase cognitive performance. Despite this, few studies postulate the effects of long term exercise habits on the cognitive performance of young adults.

To understand the mechanisms by which exercise may improve mental performance, affected neurotransmitters have been investigated in a variety of studies. Overarchingly, it has been found that the monoamines serotonin, dopamine and norepinephrine all are modulated by exercise in various ways. More specifically, it has been observed that these monoamines are able to enhance plasticity in the central nervous system when a person partakes in chronic moderate exercise [5]. In contrast, intense overexercising has the reverse effect, as hyperactivation of the monoamines has been observed to lead to subsequent fatigue, and in turn reduced cognitive ability [6]. Other neurophysiological measures considered included blood homocysteine levels, a molecule that is an indicative risk factor for cognitive impairment. This measure has been observed to decrease in adults who engaged in 2 months of consistent physical exercise [7], suggesting a reduced risk for cognitive impairment. Although no imaging or physiological measurements will be made during this study, it is relevant to note the basis and implications of our arguments.

It is also important to consider the common cognitive measures observed to be affected by exercise. Reaction time (RT) and reaction time variability (RTv) are both well known measures of individual cognitive state, RT being the time measured from a stimulus to the achieved motor response, and RTv being the inconsistency in an individual's RT. It has been found that RTv specifically has the ability to measure an individual's cognitive and motor engagement. When this value is low, the subject can be regarded as demonstrating focused attention towards the cognitive task [8]. Existing studies have used these metrics to quantify effects on cognitive impairment due to exercise. In one 12-month interventional resistance training study, participants were observed to achieve significantly reduced reaction times in comparison to a control group [7]. Compounding this result, another study examining adults aged 50-90 concluded that reaction time variability was moderated by the aerobic fitness levels (estimated $VO2_{max}$), as well as age, of the subjects. Specifically, lower aerobic fitness was associated with higher RTv, and this effect was heightened with participant age [9].

Stimulus amplitude discrimination is also a commonly employed technique for evaluation of cognitive measure. It has specifically been utilized in studies of traumatic brain injuries [10], as well as alcohol dependence [11] to elucidate cognitive deficits. In this task, a subject is presented with two varying tactile stimuli (one on each finger) at the same time. They are then tasked with indicating which finger received the stronger stimuli. The task measures the lateral inhibition capabilities of the subject as well as functionality of the parietal lobe. Lower scores indicate higher performance. [11].

It is the aim of this study to investigate if different levels of exercise have an effect on an individual's cognitive health. Rather than solely an interventional study, the existing and historical exercise habits of college students will be assessed and analyzed to obtain a measure of exercise level and history (i.e. when they started exercising consistently). Cognitive tests measuring tactile reaction time and amplitude discrimination will be taken to identify the performance differences between students with different fitness backgrounds. To assess how the effects of acute exercise vary on the individual's cognitive performance based upon their level of fitness, all subjects will also take cognitive tests immediately following a short but exhaustive workout. Fitness levels will be further gauged using subjects' time to run a mile, and exhaustion level following the workout instructed, to get a more objective and specific measure.

We predict subjects with a history of fitness habits starting at a young age who continued these habits into their adult years will generally have increased cognitive performance compared to individuals who were sedentary growing up. Subjects who consistently work out (4-7 days/week) at a moderate to high level of intensity and have a history of exercising will witness increased performance on cognitive measure tests following a workout, whereas those who are sedentary will witness decreased performances.

Methods

45 individuals (28 female, 17 male) aged 20-28 years old were recruited for this study. It was determined through previous neurological testing that none of the subjects had any form of physical or cognitive impairment that would affect the results of this study. Subjects were instructed to use the Cortical Metrics Brain Gauge™ for cognitive evaluation, a computer-mouse shaped device that runs on a computer. The test battery contained 2 tests, a simple reaction time test and a simultaneous amplitude discrimination test. In the reaction time test, subjects clicked on their keyboard as soon as they felt a tap. For the amplitude discrimination task, vibrations are delivered to the tips of the subjects fingers and they chose which is more intense by clicking on the computer screen.

The results of these tests included several observations, including reaction time variability, that could be used to determine cognitive function of each subject. After completing the cognitive functions tests, each subject held a plank for one minute (Figure 1). This task served as exercise for the subjects. After the plank, each subject completed the simple reaction time test and amplitude discrimination tasks again. By comparing the cognitive function tests in each subject before and after the plank exercise, the effects of acute exercise on cognitive function can be investigated. In addition, after the subjects completed all of the tests, they completed a survey with several questions about their physical fitness. The questions on this survey asked about each subject's past physical activity, current physical activity, and cardiovascular strength. This survey was used to determine each subject's fitness level. The survey also asked how physically tired each subject was after the one minute plank to investigate how physical exhaustion can contribute to short-term cognitive function. Results from all parts of the protocol were used to determine how general fitness level affects cognitive function, and how short-term exercise affects cognitive function in people with higher fitness versus people with lower fitness levels.

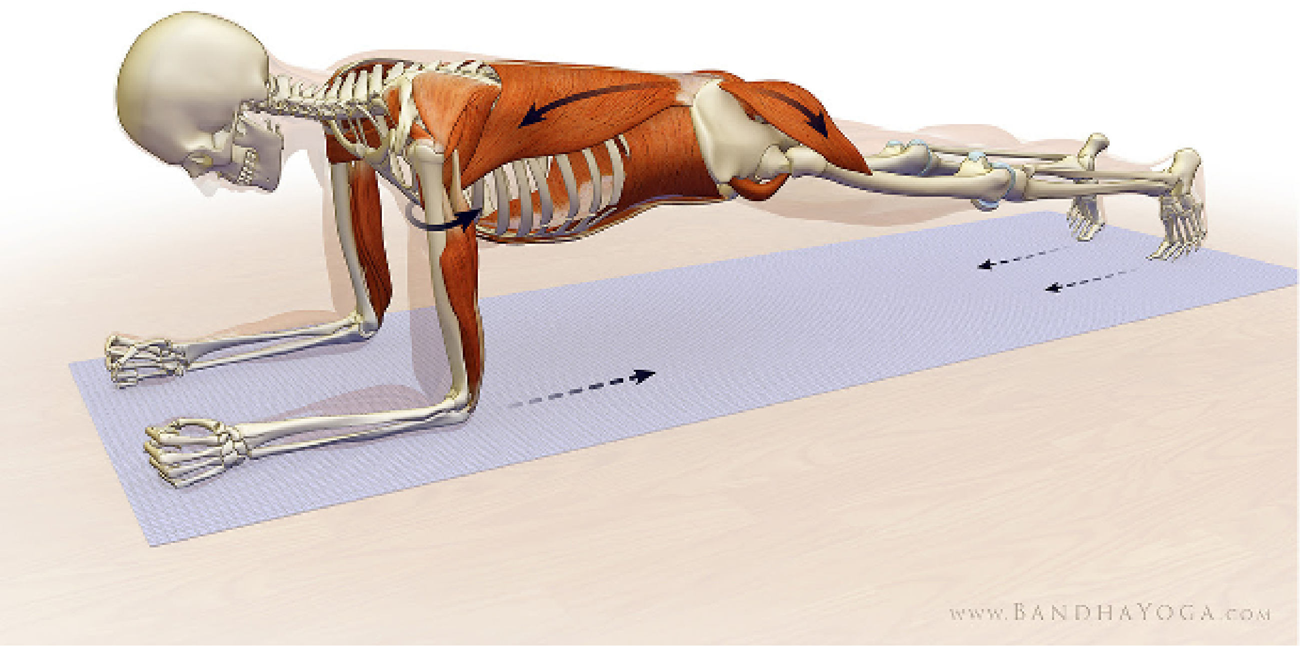

Figure 1. *Demonstration of a proper plank exercise.* [12]

(*Around your Core in 4 Minutes)*

Results

Subject fitness levels were evaluated based on the survey taken post-testing. Evaluation criteria included current fitness level (based on hours/instances a week spent exercising, mile time, and self-reported exhaustion level following plank), and history of fitness (if they participated in a sport growing up, and how many years they have exercised regularly). For as much standardization as possible, the subjects were each graded a fitness point level score based on Table 1. Since a principal focus of this study was measuring the effect of long-term fitness habits on cognitive performance, the fitness history measurements were weighted by a factor of 1.5. For representativeness, 9 subjects with lower exercise scores (between 0 and 6) and 9 subjects with higher scores (between 6 and 10) were selected for data analysis.

Current Fitness	Survey answers and Associated point values			
Hours Exercise/Week	0-2, +0	2-5, +0.5	5-7, +1	7+, +2
Times Exercise/Week	0, +0	1-3, +0.5	4-7, +1	8+, +2
Mile Time*	>10 min, +0 (F)	<=10 min, +1 (F)	>8 min, +0 (M)	<=8 min, +1 (M)
Plank	1-3, +1	4-6, +0.5	7-10, +0	

Fitness History	Survey answers and Associated point values			
Played sport growing up	Yes, +1	No, +0		
Years exercised regularly	0, +0	1-2, +0.5	3-4, +1	5+, +2
Total Fitness Level = Current Fitness + 1.5*Fitness History				

Table 1. *Quantitative measure of fitness levels for subjects, with higher point values indicating a greater performance.* *Subjects were evaluated differently for mile time based on gender, M=male, F=female.

First, to assess how simple reaction time varies with fitness levels, reaction times from the first trial (pre-exercise) were plotted against assigned fitness scores for 18 subjects (Figure 2). For comprehensive analysis, subjects were split into 2 groups, lower fitness (with scores ranging from 0-5.5) and higher fitness (with scores ranging from 6-8.5). Both groups contained 9 subjects. Means and standard deviations were calculated for each group (Table 2). The lower fitness group achieved a mean of 206.9 milliseconds and standard deviation of 39.5 milliseconds; the higher fitness group achieved a mean of 212.5 milliseconds and a standard deviation of 20.16 milliseconds.

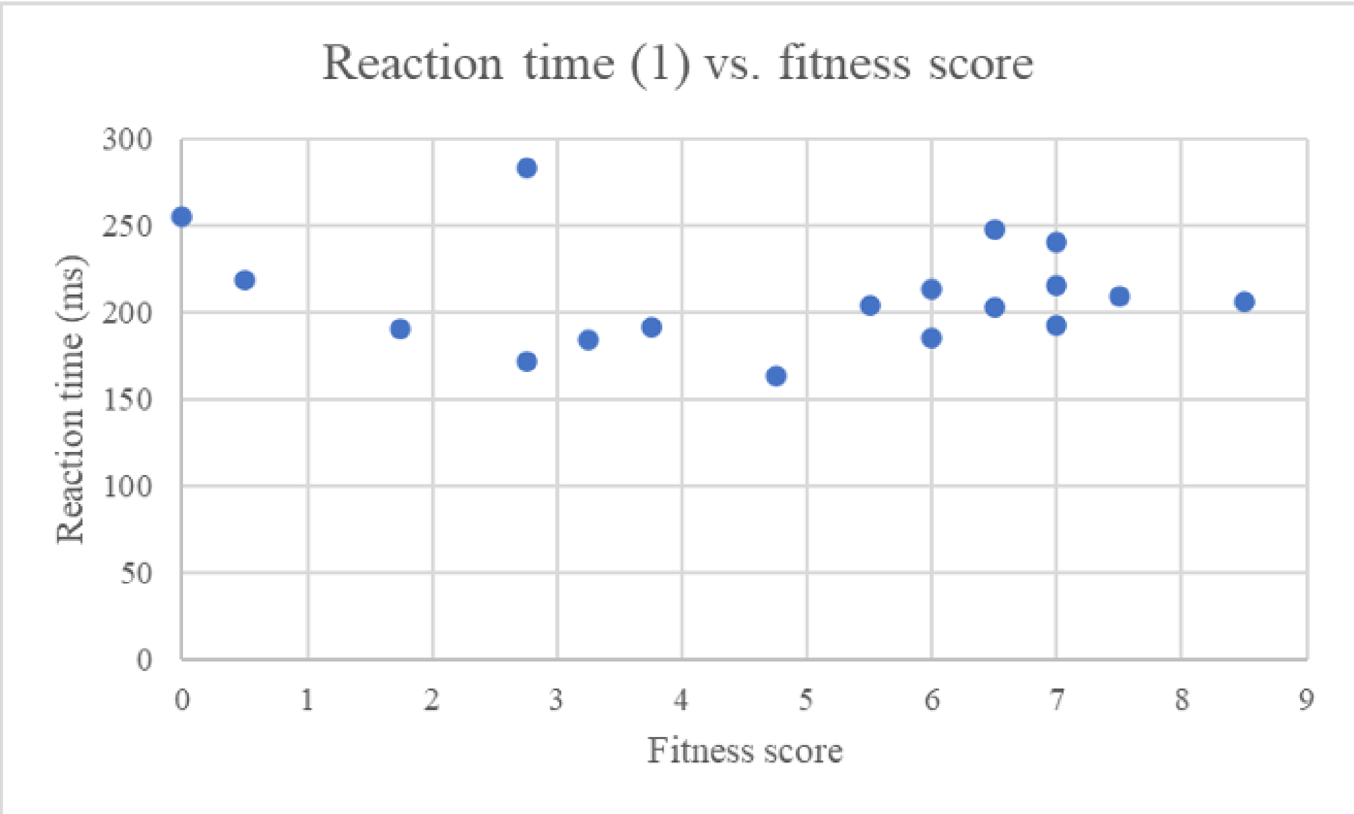

Figure 2. *Reaction time in milliseconds for the pre-exercise trial vs. assigned fitness score for 18 subjects. Lower times indicate better performance.*

Mean (ms)	Standard Deviation (ms)
Lower Fitness (0-5.5)	206.9
Higher Fitness (6-8.5)	212.5

Table 2. *Mean and standard deviation of reaction times in lower fitness groups and higher fitness groups.*

Next, to assess how stimulus amplitude discrimination score varies with fitness levels, stimulus amplitude discrimination scores from the first trial (pre-exercise) were plotted against assigned fitness scores for 18 subjects (Figure 3). Again, subjects were split into 2 groups, lower fitness (with scores ranging from 0-5.5) and higher fitness (with scores ranging from 6-8.5). Both groups contained 9 subjects. Means and standard deviations were calculated for each group (Table 3). The lower fitness group achieved a mean score of 66 and standard deviation of 32.37; the higher fitness group achieved a mean score of 37.33 and a standard deviation of 18.01. It should be noted that as evaluated by the Brain Gauge, lower scores indicate a higher performance on stimulus amplitude discrimination tasks. A one-tailed, unpaired T-Test was used to assess if a difference existed between scores for the 2 groups, resulting in a p-value of 0.0169. This is a statistically significant result on the basis that it is less than p=0.05 which is generally accepted by the scientific community, and suggests there is less than a 5% chance the results occurred by chance.

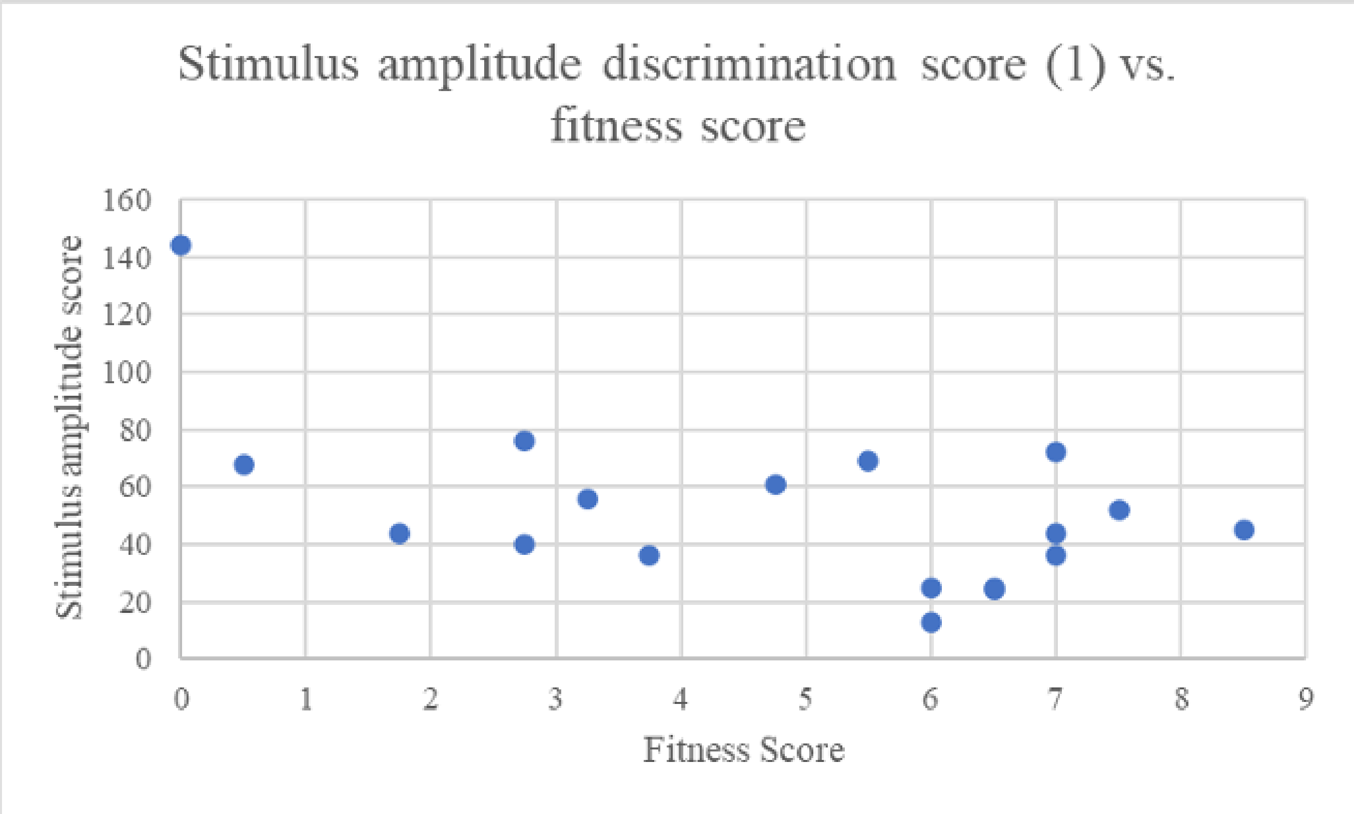

Figure 3. *Stimulus amplitude discrimination score for the pre-exercise trial vs. assigned fitness score for 18 subjects. Lower score indicates better performance as assessed by the Brain Gauge™*

	Mean score	Standard Deviation
Lower Fitness (0-5.5)	66.00	32.27
Higher Fitness (6-8.5)	37.33	18.01

Table 3. *Mean and standard deviation of Stimulus amplitude discrimination scores in lower fitness groups and higher fitness groups.*

Finally, to assess how short term intervention exercise (plank) affected reaction times of those with different exercise levels differently, the difference in reaction time variability (post exercise - pre exercise) was plotted against fitness level (Figure 4). Again, subjects were split into 2 groups, lower fitness (with scores ranging from 0-5.5) and higher fitness (with scores ranging from 6-8.5). Both groups contained 9 subjects. It can be seen in Table 4 that the lower fitness group averaged a reaction time variability difference of 6.055 seconds, indicating a decline in performance after exercise. In contrast, the higher fitness group averaged -7.20 seconds, indicating an increase in performance after exercise. Both groups observed high standard deviation values, reflecting the data variability of this study. Again, a one-tailed, unpaired T-Test was used to assess if a difference existed between reaction time variability for the 2 groups, resulting in a p-value of 0.0016. This is a statistically significant result on the basis that it is less than $p=0.05$ which is generally accepted by the scientific community, and suggests there is less than a 5% chance the results occurred by chance.

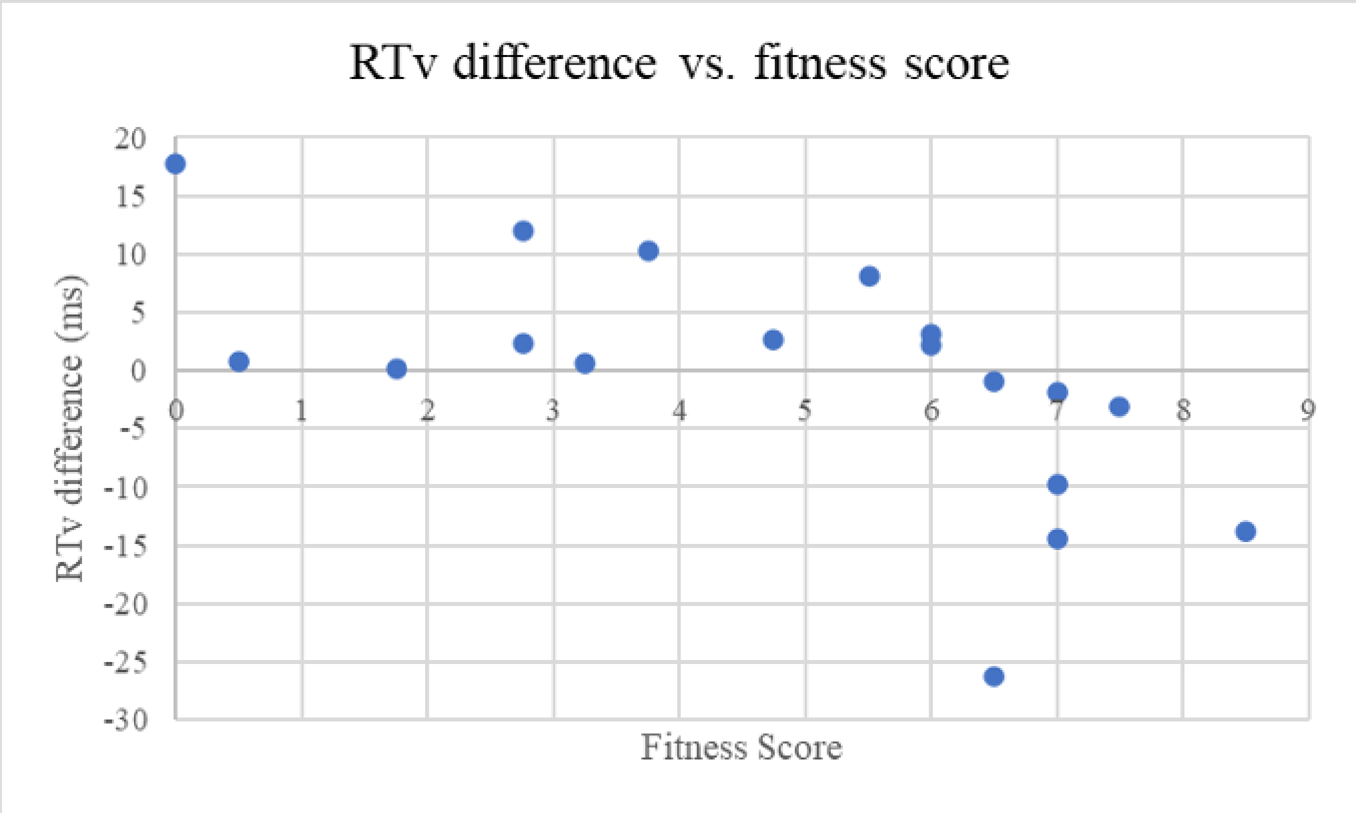

Figure 4. *This graph displays the reaction time variability difference (ms) based on each subject's fitness score.*

	Mean (ms)	Standard Deviation (ms)
Lower Fitness (0-5.5)	6.055	6.245
Higher Fitness (6-8.5)	-7.200	9.632

Table 4. *Mean and standard deviation of reaction time variability difference (ms) in lower fitness groups and higher fitness groups.*

Discussion

Figure 2, which examines how reaction time varied amongst individuals with different fitness levels, displays a general trend of reaction time increasing as fitness level increases. This general trend is the opposite of what we hypothesized, since subjects of higher fitness levels should have quicker, and therefore lower, reaction times. This trend is indicated in the mean reaction times for lower and higher fitness groups, as the lower fitness group had an average reaction time of 206.9 ms, and the higher fitness group had an average reaction time of 212.5 ms. These averages have high standard deviations, with the low fitness group's standard deviation at 39.53 ms, and the high fitness group's standard deviation at 20.16 ms. These standard deviations overlap, indicating that the trend is not necessarily significant. This result was also not statistically significant in a t-test, since the p-value of this data was 0.355, which is above the minimum statistically significant threshold 0.05. This means there is a more than 5% chance that these results were due to chance, rendering the upward trend insignificant. We did not find a valuable trend in fitness level and reaction time.

Figure 3, which displays stimulus discrimination score against each subject's fitness score, shows a general trend of decreasing stimulus discrimination score as fitness level increases. This trend matches our hypothesis, since lower discrimination score indicates better lateral inhibition, and increased ability to feel differences in amplitude. The mean discrimination score was 66.00 +/- 32.37 for the lower fitness group, and 37.33 +/- 18.01 for the high fitness group indicating average ability to discriminate between different stimulus amplitudes was better in subjects with higher fitness. However, the standard deviations were high, indicating that this data may not be significant. This data was also analyzed with a t-test, which resulted in a p-value of 0.02. This value is lower than the minimum statistically significant value of 0.05, indicating that the trend observed in the graph is statistically significant. This validates out hypothesis that cognitive ability increases with fitness levels, since there is a significant trend of better amplitude discrimination with increasing fitness level.

Figure 4, which displayed the difference in reaction time variability before and after a 1 minute plank versus fitness level, showed the general trend of the difference in RTv decreasing as fitness level increased. Since we calculated the RT variability difference by subtracting the post-plank value from the pre-plank value, a negative value for the RT variability difference means that reaction time varied less after the subject performed the plank. Therefore, the decrease in RT variability difference as fitness level increased indicated that subject's of higher fitness level performed better after the plank, which supports our hypothesis of exercise increasing cognitive ability in higher fitness subjects. The average RT variability difference was 6.055 +/- 6.245 ms in the lower fitness group and -7.200 +/- 9.632 ms in the higher fitness group. Since the average difference was positive in the lower fitness group and negative in the higher fitness group, these averages support the hypothesis that cognitive ability decreases after acute exercise in subjects with lower fitness and increases after acute exercise in subjects with higher fitness. However, the standard deviations were high for these values, indicating that these averages may not be statistically significant. A t-test was performed on this data set, which resulted in a p-value of 0.0016. This value is below the minimum statistically significant threshold of 0.05, meaning the trend is less than 5% likely to be due to chance.

Overall, our results suggested that subjects with higher fitness levels have higher cognitive function, and their cognitive function increases after short-term acute exercise, while subjects with lower fitness levels decrease in cognitive function after acute exercise. We did not find a significant trend of fitness level affecting simple reaction time, but this is likely due to our population's lack of age diversity, as most of our test subjects were either 21 or 22 years old. Individuals in their early 20's generally have lower reaction times regardless of their health, which makes differences in reaction time between high fitness and low fitness subjects hard to indicate. This was also evident in the baseline reaction time tests taken prior to this study to rule out any neurological disorders; most participants fell around the 200 ms mark consistently with normal random variation. To account for this lack of age diversity, the protocol was performed with 4 additional subjects aged 47, 52, 61, 62 with moderate levels of fitness (ranging in score from (5-8.5). However, we have strong reason to believe the results for these subjects were improperly skewed due to lack of experience with the Brain Gauge.

There were many limitations to this study. As mentioned, most of our subjects were either 21 or 22, and this lack of age diversity likely affected the performance of our subjects. There was also a lack of gender diversity, as our study included only 5 males with 13 females. This study was also conducted in several different environments, as each subject completed the test on their own time. As a result, we could not control for environmental distractions or other variables such as time of day or caffeine consumption, which likely affected the data. We were also not present when each subject performed the test, so we could not monitor the subjects to make sure each part of the study was performed correctly. Lastly, different methods could have been used to gauge fitness levels in order to get a more objective metric, such as the ones used by Bauermeister & Bunce, 2016. All of these limitations could have contributed to the results we found. However, in the two significant trends we found, the low p-values make us confident that these were not due to chance or study limitations.

Conclusion

This study showed that people with higher fitness levels have higher cognitive ability, specifically in ability to decipher between signals of different amplitudes. We also concluded that subjects of higher fitness levels perform better on cognitive ability tests after exercising, while subjects of lower fitness levels perform worse. This matched our hypothesis that cognitive ability improves with higher fitness levels. Combined with information from previous studies, our results imply working out, especially starting from a young age, can yield mental benefits in addition to the physical.

Future directions include testing a wider variety of subjects in a more controlled environment, as these components may have limited our study. Additionally, in order to get a more objective measure of fitness, physiological measures such as VO_{max}, heart rate or blood pressure should be taken.

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