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The Effect that Exercise has on Cognitive Functions – A Review

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Abstract

My aim for this literature review is to present and discuss a possible relationship between physical exercise and different kinds of cognitive functions. With the increasing interest on the topic, more studies have been conducted and the results from the studies have been a little ambiguous. The most part of the studies has been showing that exercise has a positive effect on cognitive functions. The evidence from the studies also says that exercise can help the brain to regulate the production of new neurons and to increase brain volume in the prefrontal and temporal areas. That can be very beneficial for elderly people with dementia, Alzheimer's disease or other cognitive declines. Evidence of exercise combined with the right nutrition can enhance cognitive performance even more but to establish this more research is needed.

*Keywords***:** cognitive functions, physical exercise, cognitive test, neurogenesis, nutrition

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1. Introduction

There is a great deal of research indicating that physical exercise helps to improve different cognitive functions in both humans and rodents. Scientists already know that exercise is good for general health and that exercise could prevent different cardiovascular diseases such as high blood pressure and heart attacks (van Praag, 2009). Despite those researchers in the west end of the last century who started to pay attention to what effect physical exercise has, it was already in 1975 that the researchers were starting to pay more attention to this kind of research. In the past fifteen years, the interest of this kind of research has increased and scientists have got a better understanding about the subject but it is still a long way to go before we know all too it (van Praag, 2009).

In this kind of research, scientists can use physical activity or physical exercise when they study the effect that physical movement has on cognitive functions. Physical activity and physical exercise are two different things. Physical activity is defined as any bodily movement produced by skeletal muscles that require energy consumption. (Hötting & Röder, 2013). While physical exercise is defined as a bodily movement to enhance or maintain physical fitness, a subcategory of physical activity that is planned, structured, repetitive, and purposeful in the sense that the improvement or maintenance of one or more components of physical fitness is the objective (Hötting & Röder, 2013). There are different kinds of exercise; aerobic and anaerobic. Aerobic exercise is swimming, walking, cycling, etc. to increase your cardiovascular strength and to maximize the capacity of oxygen uptake. While anaerobic exercise is interval training, lifting a weight, etc. to increase short term muscle strength (Hillman, Erickson & Kramer, 2008).

This essay is a literature review and to find articles I used the following databases for my search; PsycINFO, PsycArtickles, MEDLINE, ScienceDirect, Academic Search Elite and Google Scholar. The first article of interest was from 1989 so I choose to look at articles between the years of 1989-2016. I found a large number of articles 8 608 to be exact when I used the terms of physical exercise and cognitive functions. I had to narrow them down so I concentrated on the articles that had the words cognitive function and physical exercise in the title, then I just had 246 articles to sort through. Most of the articles were conducted on elderly people and not so many articles were of adolescents or of young adults the research articles I have chosen mostly use the aerobic exercise. When I first started with this article in 2012 there were 4170 articles with the same search words. That indicates that in the past 5 years the research and publications about physical exercise and cognitive function have doubled and are a more popular subject to study. I think that this is because people are in general getting older and live longer and that results in more people that have a cognitive decline that we can study. Most of the studies were conducted on people with some sort of cognitive impairment such as Alzheimer's, dementia or mild cognitive impairment (MCI). To narrow it down I have for the most part chosen studies with healthy adults without a cognitive decline.

My aim for this essay is to present and discuss a possible relationship between physical exercise and different kinds of cognitive functions. The main focus of the essay will be to present some cognitive functions, to look at the correlation between cognitive functions and physical exercise and what is happening in the brain during exercise. In the essay, I have five sections that I am interested in. The sections are cognitive functions, different types of measurements used to measure cognitive functions, studies that discuss physical exercise and cognitive function and what effect they have on each other, different mechanism and what happens in the brain when we exercise in the end I will have a small section to look at the benefits of nutrition, physical exercise, and cognitive functions. The essay will end with a discussion and a conclusion.

2. Cognitive Functions

The term cognition and cognitive function are how we operate in the real world and what makes life richer (Weisberg & Reeves, 2013). It describes how the brain processes information and our ability to perceive the world with a number of different cognitive processes that can be both conscious and unconscious. The different cognitive processes are thinking, language, memory, learning, attention, perception, and reason. Through these processes and by learning new skills we continuing to develop our cognitive functions and the performance of our cognition during most part of our life, but when people get older our cognitive functions start to decrease. The research focus of cognitive functions is mostly on ways how to improve ability, memory, and learning by a number of different factors such as sleep, exercise, chemicals, medicine or diet. A lot of research has also been done on cognitive declines that are known to have a negative effect on cognitive functions such as Alzheimer's, Parkinson's, diabetes, dementia and depression for trying to understand how we can prevent this from happening (Coviello, 2018).

Even if there is a number of different cognitive process that is included in cognitive functions I have chosen to narrow it down in my literature review. So I am focusing on the different cognitive processes that are the most common in experimental studies and in cognitive function tests. I will look at two different processes of memory, short-term (working memory) and long-term memory (only referred as memory later in the text), I will look at the process of attention and information processing speed and the process of executive functions.

Executive functions defined by Smith et al., (2010) and Mizuno et al., (2011) as a set of cognitive control processes that monitor goal-directed behavior. The cognitive processes associated with executive functions are located in the pre-frontal cortex and is necessary for the control of behavior and include different areas such as attention, working memory, error detection, problem-solving, reasoning, and planning. The area of the prefrontal cortex is an area that declines with age and so does the cognitive processes.

The human memory serves as a workplace where we can do our moment to moment activities, an example of this is how we can decide how we best can remember material for a test or how we in a specific moment keep track on a conversation that we are having with another person. Usually, we use our memory without thinking about it, but when our memory malfunctions we stop and get conscious of our memory. We usually talk about memory as in a single word but the human memory is built of three separate structures, sensory memory, short-term/working memory, and long-term memory. Sensory memory has set a time limit of milliseconds to seconds to recover what someone else said right before, sensory memory consists of echoic auditory memory that can hold information up to 2 seconds and the iconic visually memory that lasts for about 300 milliseconds. All memories are first stored in the sensory memory and then can be moved into short-term or working memory as it also can be called by attentional processes (Weisberg & Reeves, 2013). Gazzaniga et al., (2009) and Smith et al., (2010) defines working memory as short-term storage and manipulations of information an ability to remember and process information. It is readily available to conscious awareness for a short period of time, typically 10-15 seconds up to one minute. It has a temporary and limited capacity and can only hold about seven items (+-2) and can be a person's name or a phone number.

If the information is a more familiar and meaningful type such as digits, letters or words, it can affect the capacity to a greater memory span and if the information is in a more unfamiliar like sounds or random shapes you get lesser memory capacity. During different cognitive operations, we use the working memory to process information and working memory also plays a large role in almost every cognitive process because of its role of consolidating memories to the long-term memory (Weisberg & Reeves, 2013). The Short-term/working memory that is being rehearsed can consolidate into long-term memories through the consolidation process in the hippocampus over time. The hippocampus looks like a seahorse and is located in the medial temporal lobe. The hippocampus receives information from the cortex and the nearby regions and over time tie them together into a more stable long-term memory. The hippocampus is particularly involved in learning and episodic memory (Gazzaniga et al., 2009).

The long-term memory is divided into declarative (explicit) memory is personal and world knowledge that we have conscious access to and non-declarative (implicit) memory is motor or cognitive skills that we do not have conscious access to. Declarative memory is to know what a thing or place is and it defines as retention, recollection, and recognition of previously encountered information such as events or facts. The declarative memory is broken down to two subcategories: the first is episodic memories that are memories of different events and experiences from a particular time and place of a person´s life, and the second is semantic memories that are different kinds of facts such as world knowledge, object knowledge or language knowledge. Non-declarative memories are divided into four subcategories: Procedural memories that involves motor and cognitive skills such as how to ride a bike or how to read, perceptual representation system (PRS) that is perceptual priming such as the ability to identify a stimulus because of earlier exposure to that stimuli, classical conditioning or Pavlovian conditioning that is conditioned responses between two stimuli and at last non-associative learning that consist of a habituation and sensitization two easy forms of learning (Gazzaniga et al., 2009).

Attention is a sort of executive process that people need to deal with the world by planning and carrying out cognitive and motor processes. Attention can be divided into two processes: selective attention that is the ability to focus on specific stimuli and ignore irrelevant stimuli and divided attention that is a sort of multitasking where we try to achieve multiple things at the same time (Weisberg & Reeves, 2013). An example of attention is how god a participant in a study attends to the correct target stimuli compared to neutral or distracting stimuli. Attention and information processing speed define by Smith et al., (2010) as the sustained focus of cognitive resources with selective concentration and rapid processing of information. An example of information processing speed can be the time it takes a person to do a cognitive test or other mental tasks.

3. Methods to Measure Cognitive Functions

The different kinds of methods that can be used to measure cognitive functions are different cognitive tests such as the Animal naming test, where you get the participant to name as many animals as possible 60 seconds. The score is the total number of animals named. This test assesses not only verbal fluency but also memory and executive function. (Hoffman et al., 2008).

The Stroop task is an information processing test and measures the sensitivity to interference and the ability to suppress an automated response and usually is conducted on a computer screen. The Stroop task consists of three lists, one-word list, one color list, and one interference list and two levels that both have the test word in the center of the screen. The levels are the simple level that consists of 20 stimuli and include the word list was and the participant has to read a list of color words as quickly as possible and the score is the total number of words read in 45s. The more complex level that contains 40 stimuli and involves the color-interference list. The color list has required the participant to name the color of a series of colored bars in 45s. The interference test contained 40 stimuli and consists of a series of color words, but the words are colored in different ink than the color they are referring to. Participants are required to name the color of the word but not the word itself. The Stroop test color interference level is used to measure selective attention and executive function. (Cooper et al., 2016; Hoffman et al., 2008).

Controlled oral word association test (COWAT) is when participants would generate as many words as possible. They start with a specific letter in the 60s and then they do this procedure with three different letters. It tests executive function and memory (Hoffman et al., 2008).

The Eriksen flanker task can show how ignored information can influence the processing by the interference of the attended information. The stimuli consisted of a list of letters and all letters were presented on a computer screen. The flanker task also includes two response buttons one for the participant's left hand and one for the participant's right hand. The target letter is in the middle and need a response such as a press on the right button when the target is the letter A and a press on the left button when the target is letter E. The nearby distracting letters can be all the same (congruent) as the target or if the letters are opposite (incongruent) the target letter and is measured by the reaction time that it takes to respond. Participants were instructed to attend to the center target letter and press the different buttons (left or right) depending on which target letter that appeared (Gazzaniga et al., 2009).

The Wechsler Adult Intelligence Scale (WAIS) is the gold standard for the assessment of intellectual functioning in adults, and also has often been used to assess the presence and severity of neurocognitive impairment. In the currently fourth version (WAIS-IV) the core subtests of the WAIS include: working memory test with the mean percentage of correct arithmetic and letter-number sequencing, a verbal comprehension index with the mean percentage of correct information, similarities, vocabulary and comprehension, tests of perceptual organization with the mean percentage of correct of the block design, matrix reasoning and picture completion and processing speed assessments with the number of correct items per 60 seconds of Digit-Symbol substitution. In the subtests for information, the participants need to gather knowledge and information from their daily lives. In the test of similarities, the participants describe if concepts are similar to another. In the vocabulary test, the participants are asked to describe the meaning of a term. In arithmetic's participants need to solve arithmetic questions within a time limit. In the letter-number sequencing, participants are asked to repeat up to 8 random numbers and letters and put them in alphabetical or numerical order. In block-design, the participants in a specific time need to copy a pattern using blocks. In matrix reasoning, the participants get five alternatives and need to decide which one is the most reasonable missing part of a logical sequence. In picture completion, the participants need to tell which part that has been taken out of the picture and in the digit-symbol substitution, the participants need to as quickly and accurately as possible replace numbers with symbols (Smith, Potter, McLaren & Blumenthal, 2013; Hillman et al., 2006).

The digit symbol substitution test (DSST) evaluates the general psychomotor speed and is well established by researchers in a clinical context. The DSST test consists of digits that have to be matched with either the same digit (easy level) or a symbol that has to be matched with a digit through a key showing digit-symbol pairs (complex level). In both levels, the variable of interest was the number of correct substitutions made in the time of 45 sec. (Cooper et al., 2016)

The Corsi Blocks test is a visuospatial working memory task that has been used in decades. The test consists of a 3x3 grid of 9 blocks that indicates a spatial sequence by changing the color of one block at the time. The participant was told to repeat the sequence by clicking at the block in the same order. In 12 tryouts the sequence length became longer by one block every time the participant got a correct answer in the repeated sequence. By every wrong answer on the sequence became shorter by one block (Cooper et al., 2016).

Another type of method that can be used to measure cognitive function is to measure the brain activity during the different cognitive tasks by using brain imaging techniques such as electroencephalography (EEG) where the activity in the brain was recorded from 64 electrodes sites arranged according to the international 10-10 system (Drollette et al., 2014).

Functional Magnetic Resonance Imaging (fMRI), uses related methods to detect changes in blood flow in the brain due to neural activity, which is referred to as the Blood Oxygenation Level Dependent (BOLD) signal. Diffusion Tensor Imaging (DTI), which is used to assess the integrity of specific white matter fiber pathways within the brain. Arterial spin labeling (ASL), which quantifies regional blood perfusion in the brain, and Cerebral Blood Volume (CBV), which may be a marker for neurogenesis in areas like the hippocampus. (Smith et al., 2013).

Magnetic resonance imaging (MRI) is a neuroimaging technique that exploits the magnetic properties of organic tissue in the brain. Because of the number of protons and neutrons in their nuclei, some atoms in the brain are especially sensitive to magnetic forces. So in the presence of a strong magnetic field the orientation of these atoms can be altered. When the magnetic field is removed the atoms will gradually return to a randomly distributed orientation and in the process, this transition will generate a small magnetic field that can be measured by sensitive detectors.

Positron emission tomography (PET) is a neuroimaging method that measures metabolic activity in the brain by monitoring the distribution of a radioactive tracer. Transcranial magnetic stimulation (TMS) is a noninvasive method that is used to stimulate the cerebral cortex or motor neurons. A strong electrical current is rapidly generated in a coil placed over the targeted region. The current generates a magnetic field that causes the neuron in the underlying region to discharge. TMS is used in clinical settings to evaluate motor function by direct stimulation of the motor cortex.

In summary, there are many different tests that can help scientists to measure cognitive functions and cognitive performances. This is just a handful of tests that I have found in the research that I looked through. There are many more tests that can measure cognitive performance and cognitive functions both that are well established by scientists and some that are not.

4. Exercise and Cognitive Function

The data in this section are from different studies and review articles I have looked through. They show the effect physical exercise has on cognitive functions such as executive function, attention/processing speed, working memory, and memory. The results from studies on physical exercise and its effect on cognitive functions are both positive and negative. There are different variables and types of training that you have to consider when you are studying the effect of physical exercise and cognitive functions but also the intensity of the training such as low, moderate and high. The intensity of exercise is measured in maximum heart rate (MHR) percentage where low-intensity exercise is 40-50 % of MHR, Moderate intensity training is 50-70 % of MHR and high-intensity exercise is 70-90 % of MHR (Rognmo, Hetland, Helgerud, Hoff & Slørdahl, 2004). The intensity level is also important to determining different physiological responses such as heart rate, brain-derived neurotrophic factor (BDNF) and neurotransmitters, norepinephrine, endorphins, serotonin and dopamine, oxygen uptake and physical fitness (Chang, Labban, Gapin & Etnier, 2012); McMorris, Sproule, Turner & Hale, 2011).

In a review article that Chang et al., (2012) wrote they looked at 79 different articles with data from 2072 participants on how physical exercise affects various cognitive functions. Most of the studies were on young adults with the mean age was 28,5 and the rest on adolescents and adults. Most of the effects came from studies on young adults (20-30 years old). In the review, there were around 44 different cognitive tasks conducted and some of them are the Stroop test, Erickson flanker task, Wechsler Adult Intelligence Scale and the DSST. There were three different stages of exercise that the data from the cognitive performance test were taken from, during exercise, immediately after exercise and after a delay. There were various results but all the three stages showed a positive effect on cognitive performance from physical exercise. The results during exercise the effect within the first 10 minutes of exercise was negligible and the effect was negative after 11-20 minutes of exercise but the effects after 20 minutes of exercise were positive. This was the result of cognitive tasks in general, the highest effects were in the test that measured executive functions. Effect immediately after exercise was positive only in information processing, reaction time and memory but only when the exercise was light or moderate intensity and when exercise was maximal or hard the effect was not significant. In the stage after a delay following exercise, there was a negative effect on cognitive performance if the intensity of the exercise was low and a positive effect on mediate and high intensity. The physical fitness of a subject can have a strong effect on the cognitive performance on a test because the narrow and constant metabolic capacity of the brain and the neural resources that a subject needs to perform a cognitive task competes with the capacity that the body needs for physical exercise. The largest effect of cognitive performance after a delay of the exercise was on executive functions. During exercise and immediately after exercise the fitness level of participants had a moderate effect such that fit participants got better effect and low fit participants got a lower effect. The fitness level in the stage after a delay of exercise had no effect on the results (Chang et al., 2012).

In the review by Smith et al., (2010) they looked at 29 different studies that had data from a total of 2049 participants. The study deals with healthy older adults and how aerobic exercise with a duration from 6 weeks up to 18 months, affect cognitive functions. The most common aerobic exercise was brisk walking and/or jogging and the control groups were typically assigned to a waitlist but also to groups of stretching and toning, health education and relaxation exercises. The different studies that were looked at included several different cognitive tests such as, DSST, the Stroop test, COWAT, and animal naming test. The cognitive tests measured the participant's attention/processing speed, executive function, and memory. The results of the review show a consistent effect across studies that aerobic exercise training is associated with modest improvement in attention and information processing speed, executive function and memory. But the effect on working memory is less consistent and the twelve studies conducted on working memory indicate that aerobic exercise did not improve the performance on working memory.

In a study conducted by McMorris et al., (2011) there was indirect and direct evidence from PET and fMRI studies so they compare the effect of acute intermediate intensity exercise of the rapidness and precision on working memory tasks using meta-analytical techniques. Intermediate intensity exercise is the optimal arousal of exercise 50-70 % MHR and another term for moderate intensity exercise. In this study, they used tests on working memory and executive function. And the exercise was measured by heart rate and the exercise intensity was moderate and limited to 50%-75% maximum volume of oxygen uptake. The results from these tests indicated that acute intermediate intensity exercise has a strong effect on the speed of response in working memory tasks but a low effect on accuracy for performance. The scientist believes that the reason that response in speed and accuracy are different is that there are two different processes and that they react differently on acute intermediate intensity exercise. The exercise increases the arousal witch increase brain concentration and neurotransmitters like norepinephrine and dopamine that speed the rapidness of the process. It can also be too much brain noise that has a negative effect on precision (McMorris et al., 2011).

In a pilot study conducted by Bakken et al., (2001) they examined whether aerobic training could improve spatial-motor task and visuospatial information processing to produce precision finger movement on elderly men and women, age 71-91 years old who live in a nursing home. In the beginning, there were 15 elderly subjects, 12 did go through the whole study and there were data from 10 subjects that were used in the analysis. The study was conducted during 8 weeks and the subjects were divided into one training group and one control group that didn't do any exercise training. The group training consisted of walking, stationary bicycling and callisthenic exercise such as sidestepping, mock boxing and marching in place 3 times a week with a duration from 6 minutes to 39 minutes, every training there was a 10-minute stretch cooldown. To determine the changes in finger-movement tracking and aerobic training effects two tests were conducted before and after the exercise, a finger-movement tracking test where the subject sat in front of a computer screen that showed a fixed and predictable sine wave. The subject had an electrogoniometer attached at the index finger on the subjects dominant hand when the subject did a finger extension horizontally the pointer moved vertically upward and vertically downward by finger flexion. During the test the pointer moved horizontally across the screen, each was 10 seconds long. The subject attempted to control the vertical position of the pointer to track the sine wave by using extension and flexion of the finger. The other test was a submaximal graded exercise tolerance step test (GXT) is a test designed for the elderly to determine if an aerobic training effect can be achieved with exercise. In the GXT test, there is a set of bars and 3 wooden steps the subject then has to be stepping in a specific pattern on any of the steps for a frequency of 20 times per minute for 3 minutes at each stage of the test. The test has 4 stages each of the stages is conducted after each other with 1 min rest in between. The conclusion was that there may be some improvements in finger tracking from aerobic exercise when they compared the test group and the training group. Even if there were no aerobic training effect in neither the training group or in the control group. Further research is needed on the topic to confirm the author's findings.

In a study that was conducted by Madden, Allen, Blumenthal, and Emery, (1989) they investigated the aerobic exercise effect on 85 older adults and their performance on reaction-time (RT) test of attention and memory retrieval, the experiment continued during a period of 32 weeks. The test divided into three assessment time 1, time 2 and time 3. Between time 1 and time 2 the older adults were randomly assigned to three different groups. One group with aerobic exercise (bicycle) where the heart rate was monitored during the whole time, electrocardio measured heart rate every minute and blood pressure measured every 3 minutes. One group with nonaerobic exercise (yoga) and one wait-listed group that did not do any exercise at all for 16 weeks. Between time 2 and time 3 all the older adults received a program of aerobic exercise training for 16 weeks. At each assessment time 1, time 2 and time 3 the participants were measured by an RT test involving a short-time memory test and one long-term memory test the older adults were also tested for aerobic capacity. The aerobic capacity was measured by bicycle ergometry testing that existed in 3-minute stages and heart rate monitoring. The RT task involved a letter search test (short-term memory) where the subjects required to compare a visually letter with a set of letters held in memory and a word comparison test (long-term memory) where the subjects needed to make a decision regarding the synonymy of two words. Each subject conducted the tests on two consecutive days and each session had a duration of approximately 90 minutes.

At time 1 a comparison group of the 24 young adults also did an RT task but did not participate in the aerobic exercise. The young adults were only tested once and the data analysis indicated that there was an age-related deceleration in both the letter-search and the word comparison test. After all three assessments, the scientist compared the collected data from older adults. The results of the study showed a significant increase in aerobic fitness levels, despite that the aerobic exercise training did not improve cognitive tasks on older adults.

A study conducted by Hillman et al. (2006) examined the relationship between physical activity and cognition. The participants were recruited as part of a bigger study on adult brain function and genetics of cognition where 626 adult twins and their non-twin siblings were asked to do a protocol of cognitive function testing. To narrow it down and avoid correlating results from family resemblance, only one participant from each family was chosen. In total the study had 241 individuals between the ages of 15-71 participated in tasks requiring executive function such as Eriksen flanker task, intelligence testing such as Wechsler Adult Intelligence Scale (WAIS) and a physical activity assessment that was measured in sweat index ranging from 1-4 that indicated how many times a week they were doing a physical activity: Once a week (code 1), twice a week (code 2), three times a week (code 3) and four times a week or more often (code 4). The participants had to report their physical activity by rating 1-4. The participants were asked to do a 4,5 hours of cognitive functions tests for 2 hours where they alternated with the WAIS test and Eriksen flanker task, then the participants did a 2, 5 hours of EEG testing that was conducted by trained assistants. In the analyzed data they controlled for age, sex and IQ. After controlling for confounding variables, the scientists found that age was associated with a general decrease of reaction time speed over conditions of the Eriksen flanker task. They also found that physical activity had a significant correlation with improvements in reaction time speed over conditions of the Eriksen flanker task. This research suggests that physical exercise can be beneficial for cognitive functions during early, middle and later part of a human's lifespan and may protect from age-related loss of cognitive function during older adulthood.

Cooper et al., (2016) did a study on adolescents to establish if there was a relation between moderate intensity sprint-based exercise and cognitive functions. The study on 44 adolescents in the mean age of 12,6 and recruited from a local school in England. All the students participated in an exercise training that consisted of an exercise part and a resting part. During the exercise part the students in groups of 8-12 participants completed a sprint of 10 x 10 seconds, and then 50 seconds of active rest (walking) that was repeated 10 times and at the end of the exercise the student's heart rate was recorded. The heart rate was also recorded four times after the exercise and rest trial (15, 45, 90 and 115 minutes). The experiment was conducted 60 minutes after the students eat their breakfast. In the resting part of the experiment, the students were seated in a classroom. Before the experiment began each student participated in a familiarization session where the methods of the experiment were explained. The cognitive tests were conducted after both the exercise part and after the resting part. The test consisted of the Stroop test, digit symbol substitution test (DSST) and Corsi block test that were all conducted on a computer and lasted for 10 minutes. The cognitive tests were administrated in a classroom in groups of 8-12 students. Each student had headphones to reduce external noise. The experiment was scheduled two times with seven days apart. The response on lower levels of the Stroop test containing 20 stimuli was significantly faster immediately after the sprint-based exercise and 45 minutes after the sprint-based exercise. At the same time, the higher more complex levels of the Stroop that contained 40 stimuli were faster after the sprint-based training. The results on accuracy had no effect in both the exercise group and the rest group in all three of the cognitive tests (The Stroop task, DSST test, and the Corsi block test). The results of the experiment indicate that response time that is an executive function in the exercise group was significantly higher than the resting group both immediately after the sprint-based exercise and 45 minutes after exercise.

In a study that Chang et al., (2014) did on 36 healthy adults in college to determine if there were is a relationship between acute exercise and cognition. The participants had to finish a Physical activity readiness questionnaire (PARQ) and a Health screening questionnaire

(HSQ) a maximal exercise test to determine in which fitness group the fitted. The participants were categorized in low, medium and high cardiovascular fitness. The group described as having poor, good and super fitness for men and poor, excellent and superior for women according to American College of Sports Medicine guidelines. The exercise test consisted of bicycle riding. First, the participants did 5 minutes of warm-up, then 20 min of medium intensity exercise about 65 % and then finish with 5 minutes of slow-down. Before and after the exercise the participants did the Stroop test. The results showed that all the participants were better at the cognitive test after the exercise in all fitness levels. Results showed that participants with a medium fitness level had the best reaction time because fitness level may play a role in executive control that is needed in the Stroop test. The participants with an already high level of cardiovascular fitness showed the lowest improvement in the Stroop test indicating that high fitness is associated with poor performance for this kind of executive control measurement.

In summary, there are many different aspects that you have to consider when you look at the correlation between cognitive function and aerobic exercise. That can be when the cognitive test is done, before or after the exercise and/or which cognitive test that is done. An aspect is the intensity of the exercise and intensity of exercise also important to determine different physiological responses such as heart rate, oxygen uptake, physical fitness, BDNF and neurotransmitters such as norepinephrine, endorphins, serotonin, and dopamine (Rognmo et al., 2004). Another aspect to consider is the participant's age or if they have any cognitive decline or disease.

5. Possible Mechanisms

The section possible mechanism describes what may happen in the brain during physical exercise and how it can affect our cognitive functions. In this section, I will go through a couple of mechanisms in the brain that is being affected by physical exercise.

It is known that the hippocampus plays an important role in processing memory. It consolidates new short term memories into new long term memories. For a long time, it has been hypothesized that neurons in the hippocampus are plastic and that they have the ability to change their synaptic interaction. Fibers from the granule cell, a part of the dentate gyrus, connects to the hippocampal cells pyramidal cells. With this system, scientists can further examine synaptic plasticity of the brain (Gazzaniga et al., 2009)

5.1. Neurogenesis, Hippocampal Plasticity, and Exercise

All the studies with different experiments I found and chose to examine in the area of neurogenesis, hippocampal plasticity and exercise were conducted on rodents (mice or rats) in different ages and different kinds of exercises. In a study by Naylor et al. (2008) the results indicate that voluntary running has an effect both on the structure and function of the hippocampus area after irradiation in young mice. It is a common treatment with cranial radiation on children with cancer that can lead to cognitive impairment that is linked to the hippocampus a region that is important in memory functions and learning. A study on prenatal mice that were exposed to radiation and after 9 weeks, half of the mice were introduced to running wheels and the rest was not. Postnatal day 9 after irradiation the mice were evaluated both by the acute effect of the radiation and the effect of voluntary running on hippocampal neurogenesis, then 3 months after irradiation the same evaluation was conducted. The evaluation showed that voluntary running significantly restored neurogenesis levels after a clinically relevant moderate dose of radiation. The study also showed that disrupted structural integration of immature neurons in the hippocampus was reversed by voluntary running.

In the 1960s Joseph Altman was already studying neurogenesis and examining whether the human brain is capable of producing new neurons. Joseph Altman conducted several studies that included rats to confirm his thesis. Joseph Altman hypothesis suggested that the plasticity and memory mediate throughout interneurons that are created postnatal in the cerebellum, dentate gyrus or the olfactory bulb that are associated with a number of functions such as locomotor memory located in the cerebellum, fixation of behavioral patterns related to emotion needing functions that's located in the hippocampus and olfactory bulb, but not to memory processes related to cognitive functions (Bordely, 2006). In the review of adult neurogenesis by Bordely (2006) she looked at the historical perspective, the cellular architecture, the identity of neural stem cells, endogenous signals, the impact from the outside world and why neurogenesis persists. She came to the conclusion that because significant development to understand adult mature neurogenesis in the last decade, the researcher has a better understanding in the environments control of mature neurogenesis and how that can give a reason of the function of constant neurogenesis in healthy brains.

By doing a physical exercise you enhance cell genesis that is associated with higher hippocampal synaptic plasticity, in particular, long-term potentiation (LTP). LTP is a physiological model influenced by the physical exercise of learning and memory. Studies with both forced and voluntary treadmill running were conducted on mice and the result was the same, both had increased LTP and neurogenesis in the dentate gyrus. In the same area, synaptic plasticity occurred, suggesting that newborn cell has a role in the process (van Praag, 2008 and van Praag, 2009).

In a study on mice conducted by van Praag, Shubert, Zhao, and Gage (2005) investigated if voluntary wheel running could be beneficial for mice that were sedentary until the age of 19 months. In the study, they used 15 young mice (3-month-old) and 18 old mice (19-month-old) and the mice were put in cages with and without running wheels. The running mice had access to the running wheel for 45 days and the distance was electronically monitored. All the mice have daily injected with bromodeoxyuridine (BrdU) retroviral labeling in conjunction with specific neural markers to label newly born cells during the first week. After 1 month (between day 35 and 39) both the running and the sedentary mice were tested in the

Morris water maze in which mice are trained to find a hidden platform under the surface in a pool in which the water is colored with paint. Over time the mice learn to find the hidden platform based on cues on the wall in the testing room. The result showed that the running mice had an increased response than the control mice without a running wheel. The positive BrdU cells in the dentate gyrus were counted and the results showed that the number of cells was more pronounced in both young and old running mice. The decrease of neurogenesis in older mice reversed by 50 % with the wheel running mice. The study indicated that by the voluntary running on older mice had a faster acquisition and preservation of the maze than the matching control mice.

In the article van Praag (2009) discussed that there is increasing evidence from research that the neurogenesis has a role in learning and memory and by increased neurogenesis, you get better cognition. Mammalian brains produce new neurons in the olfactory bulb and in the dentate gyrus of the hippocampus throughout life. But there are many different factors that regulate the production of new neurons and the loss of new neurons results in spatial memory deficit. Exercise is one of the strongest neurogenic stimuli.

In some studies, they use wheel running rodents to examine the pattern of production and survival of new neurons in the dental gyrus of the hippocampus. The cell genesis is rapid and it peaks at 3 days, then after 32 days of running, it has returned to baseline. Mice that exercised from a young age until old age the normal decline was significantly lower than the mice that were sedentary and the mice that started exercising in middle age hade an increasing number of new neurons (van Praag, 2008) (van Praag, 2009).

5.2. Brain Volume, Gray and White Matter

It is widely known that with old age comes a fading memory and decreased cognitive functions. After the third decade of life, the brain starts to lose tissue in the temporal, frontal and parietal lobes. In a study conducted by Colcombe et al. (2006) they investigated 59 healthy sedentary and voluntary people in the age between 60-79 years old in a 6-month trial to examine if aerobic exercise would increase brain volume in areas associated with age-related decline. Half the participants were randomly assigned to an aerobic training group to increase cardiorespiratory fitness, the other half was in an anaerobic toning and stretching group and 20 young adults served as a control group. MRI was used in order to see the changes in the white and gray matter of the brain. Images were collected both before and after the 6 months of training. The results indicate that by doing aerobic exercise even for just 6 months, brain volume in both gray and white matter in prefrontal and temporal areas are increasing in older adults, but there are no significant changes found in the group of middle-aged control people or the older adults with anaerobic training.

It is in the frontal and prefrontal areas of the brain that the gray matter shrinks the most when aging and the white matter shrinks the most in the temporal and posterior areas of the parietal lobes (Colcombe et al., 2003). According to the review by Peters (2005) "*A healthy life both physically and mentally may be the best defense against the changes of an aging brain*" (p. 84). This implies that there are some protective factors that can reduce cardiovascular risks such as regular exercise, a healthy diet and a low regulated intake of alcohol. After the age of 40, the brain starts to shrink with about 5 % of its weight every decade. Peters reviewed more than 43 studies to look at how the brain was affected by aging and found that there were most changes in the prefrontal cortex the area associated with executive functions and memory. He found that the loss of gray matter reports regularly through dead brain cells but it is not clear if it is just that. To get the results the researchers from studies Peters reviewed used longitudinal studies with two MRI scans, one or two years apart that showed brain changes on the brain of young adults about 30 years of age and old adults with the age of 60 years.

In summary, this section talks about what really happens in the brain when you exercise. The brain and the body is both beneficially from exercise. Exercise helps to regulate the production of new neurons and is a strong neurogenic stimulus (van Praag, 2009). Exercise is shown to reduce cardiovascular risk (Peters, 2005). Doing aerobic exercise even for just 6 months, brain volume in both gray and white matter in prefrontal and temporal areas are increasing in older adults (Colcombe et al., 2006). Naylor et al., (2008) show in his study on mice that exercise can restore neurogenesis levels after radiation which can be very good for all the people that need radiation treatment for cancer or other diseases. It has later been confirmed that the adult human brain is capable of producing new neurons throughout life (van Praag, 2005).

6. Nutrition, Exercise and Cognitive Functions

We have all noticed that if we consume a meal it will change our mood, we get higher exercise capacity and we have more motivation to do things that if we were hungry. There have been studies with findings that suggest that special kinds of food, such as fish oil with omega-3 fatty acids, teas, fruits, folate, spices and vitamins can show a positive effect on brain function, especially plant-derived products such as grapes, blueberries, strawberries, and cocoa which have been shown to increase memory in rodents (van Praag, 2009).

In the review conducted by Lieberman (2003) he investigated if soldiers from the US army and from European armies who carry out intense physical activity and needed high levels of energy while training. The studies examined looked at acute effects of the substances amino acids tryptophan and tyrosine, caffeine and carbohydrates and how they affected cognitive functions such as alertness, vigilance, and resistance to stress. Because nutritional interventions are more acceptable than drugs military scientist have instead conducted research on cognitive effects of food ingredients and dietary supplements. The greatest progress to counteract cognitive deficits during military operations was made with caffeine. Caffeine has an unambiguous effect on vigilance and enhanced cognitive functions in soldiers with sleep deprivation, these results were based on research from military laboratories reviewed by the Committee on Military Nutrition Research (CMNR). One example of these studies demonstrated that if you gave one single dose of caffeine to a sleep-deprived military volunteer the vigilance improved the following 2 hours. A study on a military unit that included a carbohydrate sports drink named ERGO and exercise training that expend a high level of energy designed to simulate an infantry combat operation. The exercise included running, marching, and a live fire rifle marksmanship test and lasted 10 hours. The study consisted of 143 male volunteers and was randomly divided into three groups that six times during the test day received a placebo drink, a 6 % carbohydrate beverage or a 12 % carbohydrate beverage. The results of the study showed that the effect was dose-related because the effect in vigilance in the group of 6 % beverage had intermediate results between the lower group of placebo and the higher group of 12 % beverage. This indicates that carbohydrate foods appear to enhance cognitive performance in soldiers engaged in sustained, intense physical activity that expends a high level of energy.

Thus that we know that a healthy diet and exercise have a beneficial effect on the body and the brain there are still not so many scientists that look at this. Gomez-Pinilla (2011) did a review of published studies on humans and animals on what the combined effect of exercise and diets have on brain plasticity and cognitive abilities. A crucial part of supporting cognitive abilities such as maintaining learning and memory is the molecule brain-derived neurotrophic factor (BDNF). Different dietary supplements and exercise have the power to impact the BDNF to neural repair and energy control, dietary and exercise also helps to maintain synaptic function that is underlying cognitive functions. The overall results showed that exercise and selective diets are good for the health and the plasticity of the nervous system. The exercise and diets are affecting the molecular events related to the management of energy metabolism and synaptic plasticity. Selective dietary factors share similar mechanisms with exercise and can even complement the action of exercise. A healthy diet and physical exercise are thought to benefit neuronal function. But the combination of diet and exercise can deliver an even more beneficial effect than they too alone. The most studies are conducted on exercise and diet is on omega-3 fatty acids, polyphenols, curcumin, and saturated fats.

Veasey, Gonzalez, Kennedy, Haskell, and Stevenson (2012) did a study of the effect that breakfast and exercise have on cognitive functions and mood. The study on 12 active men that completed four different trials. No breakfast and 2 hours of rest, breakfast and 2 hours of rest, no breakfast and exercise consisted of treadmill run or breakfast and exercise consisted of treadmill run and after the participants had a chocolate drink with 90 min rest before going to lunch. During the test cognitive performance and mood were examined. The mood and cognitive performance tests such as Simple reaction time, Stroop task, four-choice reaction time, N-back, rapid visual information processing task (RVIP) and mood and physical state scales took about 13 minutes to complete. Mood scales and the other cognitive performance tests were conducted on a laptop computer and all responses were recorded with a button response box. There were buttons for yes/no, left/right, Blue/green/yellow/red and a central reaction time button. The result of the study showed that mental ratings were higher when not eating breakfast because when the participants didn't eat breakfast before exercised they suppressed the hunger.

Watson, Kennedy, Haskell, and Scheepens (2012) conducted a double-blind placebo control study to evaluate the effect that two berry extracts have on cognitive functions and mood. The test was conducted on 35 healthy young adults. The participants arrived with a 12 h fasted to do the initial test. The participants were divided into 3 groups and were consuming a powered berry extract, a juiced extract or a placebo with sugar and flavor matching to the other groups. After 60 minutes participants completed a 70 minutes long cognitive assessment on a computer that included an attention task, a rapid visual information task, and a digit vigilance task. Both berry and juiced extracts improved in attention tasks, accuracy during visual information processing tasks and reaction time task on the digit vigilance task when compared to placebo.

In summary, there are not many or reliable studies on the effect nutrition combined with exercise has on cognitive function or cognitive performance. The results on cognitive functions that come from exercise can be enhanced by eating the right food, but it is not so well accepted because there is not enough research that confirms the thesis (van Praag, 2009).

7. Discussion

My purpose in this essay was to present and discuss a possible relationship between physical exercise and different kinds of cognitive functions. The results from the research I looked through have been a little ambiguous but most of the review articles and the original articles have shown that there is a positive effect on the correlation between exercise and cognitive functions. The results are ambiguous in that way that some studies have shown little or no effect of exercise on cognitive functions or cognitive performance. When you look at cognitive functions there are so many different tests, measurements and different types of physical exercise that there may be different tests that fit better with each other. In the last decades, there has been a significant increase of studies of physical exercise and cognitive functions and that is probably because people of today are getting older and older compared to how it was about a century ago. Because there are so many different ways to measure the effect of exercise on cognitive functions we are going to have a lot to research and many of the results are still going to be ambiguous. The upside of the rising age of our elderly is that there are so many more people to study and that can help scientists to understand how and why our brain is decreasing in both volume and function when we get older. If we then can reverse the tissue loss in the brain that comes with age we can prevent or reverse the different diseases that come with brain deprivation such as dementia or Alzheimer's.

The biggest review article I found was conducted by Chang et al., (2012) and they evaluated 79 different articles with data from 2072 participants and came to the conclusion that in three different stages of exercise (during exercise, immediately after exercise and after a delay) there were positive effect on the participants cognitive performance.

As early as Madden et al., (1989) study of adults that showed a significant increase on cardiorespiratory fitness but in the reaction-time task, attention and memory task the adults showed a slower retrieval as in the control group with the 24 younger adults, from a 16 week long aerobic and non-aerobic training program.

Aerobic exercise training shows modest improvement in neurocognitive functioning such as attention and processing speed and executive functions. It has been shown that when you exercise, several things happen in the brain. Exercise enhances the production of new neurons both by voluntary exercise and forced exercise. When you are doing a physical exercise you can produce new neurons and during learning tasks, new cells are activated. One of the strongest stimuli that increase neurogenesis is exercise and it is said that by increase neurogenesis you got better cognition (van Praag, 2009).

Bordely (2006) came to the conclusion that because significant development to understand adult mature neurogenesis in the last decade, the researchers have a better understanding in the control of the environment of mature neurogenesis and how that can give a reason of the function of constant neurogenesis in healthy brains. The research by Naylor et al., (2008) shows the effect that voluntary running has on the structure and function of the hippocampus area after irradiation. The results also showed that running restored neurogenesis levels and that immature neurons in the hippocampus were restored after irradiation treatment. So if we do more research on this topic that came to the same conclusion, physical exercise may be considered as a rehab process after radiation treatment. This can lead to improved methods and strategies that clinics can use successfully in self-repairing of damaged brains. In most of the studies the effect of exercise is positive and that you enhance cognitive performance in executive function, attention, and processing speed, working memory, and long-term memory.

In future research, they should look at which processes that are involved in what, they should try to define them. Then they should do more studies that can support and strengthen the findings that already been found. There have to be more studies on people of different ages and to see in witch age there is most beneficial to the brain to exercise and what type of training that is necessary.

Limitations of these kinds of studies are that there are not enough studies and not enough data that can support the hypothesis properly. We also know that nutrition plays a small role in some of these results because cognitive performance can be enhanced by eating the right food but there are not enough studies conducted on dietary and exercise effects on cognitive functions. The study by Watson et al., (2012) showed progress in cognitive performance with different types of berry extracts and Lieberman (2003) studies on soldiers showed enhanced cognitive functions by eating carbohydrate food and to consume caffeine. To establish the results and the effect more research is required to establish all effects that exercise has on cognitive function.

8. Conclusion

The conclusion of this literature study is that it is good for people to exercise. It positively enhances different cognitive functions and cognitive performance. It also enhances brain growth and neurogenesis in the hippocampal area in the brain that is associated with memory. Furthermore, the results of different studies have both positive and negative outcomes. The most part of the research articles that I looked at was positive and some of the studies highlight that the right nutrition combined with physical exercise can further enhance cognitive performance and cognitive functions. The topic of exercise and cognitive functions is in my opinion worth to look deeper at because of the increasing age of the population.

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