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The Effects of Physical Exercise on Cognition

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It is fairly common knowledge that physical activity has been linked to the reduction and prevention of health troubles such as cardiovascular disease and obesity. Positive correlations have even been made between physical exercise and the alleviation of colon and breast cancer (Amen, 2005). However, a lesser-known but equally true fact is that physical exercise not only protects the body from physical harm, but also affects brain function and cognition. For the better part of the 20th century, the neuroscience dogma reasoned that the brain could not grow new neurons after a certain age. Based on this theory, researchers believed that once age-related diseases such as Alzheimer's began to have their effect, there was little that could be done to slow or reverse this downward mental progression. In light of recent discoveries in the neuroscience community, however, this common perception has changed (Begley, 2009). It has been shown that the human brain can change much later in life than previously accepted and, according to Daniel Amen's "Making A Good Brain Great," physical activity "is perhaps the single most important thing you can do to keep your neurons healthy over time" (Amen, 2005, pp. 122). Based on evidence from human and animal studies, there is now significant research that suggests a positive correlation between acute physical exercise, especially aerobic exercise, the improvement of cognitive function and the deterrent of deterioration for mental processes in aging adults (Amen, 2005; *Geriatrics*, 1999; Hillman, et al. 2008).

Neuroplasiticity in Animal Studies

For as long as the brain had been studied, the long-held opinion of scientists was that the human brain stopped growing relatively early in life. While most types of cells, for example muscle or skin cells, continue to grow throughout a lifetime, it was thought brain cells were no longer produced by the time a person reached adulthood (Begley, 2009). Scientists longed for a way to test this hypothesis, and the discovery of DNA in the middle of the 20th century provided a method to do exactly that. In order for a new cell to be created, the necessary parts must be brought together to form DNA. One vital ingredient is thymidine, which also binds to radioactive material that causes it to glow a distinctly different color than old cells (Begley, 2009). Through the 1960's and early 1970's, a scientist named Joseph Altman conducted research using this very technique on adult rats and guinea pigs (Begley, 2009). When initially published, the neuroscience community quickly discarded his papers, claiming they were inaccurate and his experiments were poorly done; this discouraged Dr. Altman from further pursuit of neuroplasticity research.

In the 1980's, a scientist named Fernando Nottebohm used similar research techniques as Dr. Altman, but this time focusing on birds. His research turned out to be more conclusive than Altman's with the discovery of new neurons present in multiple locations of adult songbirds' brains (Begley, 2009). Dr. Nottebohm's research not only supported the hypothesis for creating new brain cells, but also supported the likelihood of integration of these new cells with mature ones (Begley, 2009). The new neurons were found in the hippocampus, which was believed to be the place new brain cells were created, and in the auditory regions of the brain responsible for learning new bird songs. Yet Nottebohm's research was still discarded because many scientists argued that even if birds could create new neurons, it did not mean that humans have the ability to do so. Not long after that, a scientist named Elizabeth Gould discovered hints of new neuronal growth in adult rats and primates (Begley, 2009). Gould's research moved the evidence closer to humans on the evolutionary timescale, but it was still not enough to convince the majority of the scientific community that humans were capable of growing new neurons.

While the scientific community was debating neuroplasiticity in human beings, a man named Fred H. Gage sought to conclusively find the root cause of the growth of new brain cells in adult rats. Once animal-related research had shown that neuroplasticity was possible, Dr. Gage considered enriched environments, particularly those with exercise equipment, as the reason for increased neuronal growth with positive effects on the learning and memory regions (Begley, 2009).

Dr. Gage and his colleagues decided to isolate exercise as the possible factor and found that rats that exercised had twice as many new neurons in their hippocampal region as those that did not exercise (Willdorf, 2001). In the experiment, Dr. Gage divided the rats into two groups. One group lived in barren cages and the other was given access to a running wheel. The rats grew to an age of 18 months, which is considered the equivalent of 65 in human years, and were then killed in order for their brains to be dissected. The rats were injected with an indicator late in life, which would be used to decide whether new brain cells had been created. The rats in the cages with running wheels grew new neurons at double the rate of the control group of rats (Begley, 2009). Dr. Gage was able to not only provide evidence in support of neuroplasticity, but also provided the most convincing evidence for the cause of neuroplasticity—physical exercise.

<u>Neuroplasticity in Humans and Links to Physical Exercise</u>

Long before Dr, Gage's study on rats, scientific inquiry of the relationship between physical exercise and cognition in human beings had been taking place. Although this inquiry began in the 1930's, but it was not until the 1970's that evidence of a possible link was gathered through systematic examination (Begley, 2009). The evidence came from a simple test of psychomotor speed in older adults. This test judged the participants based on reaction time and suggested that physically active older adults reacted more quickly than those who were sedentary.

In 1986, a study by researchers at the University of Southern California in Los Angeles looked at the effects of physical activity over a 12-week period on cognitive function for senior citizens (*Geriatrics*, 1986). The older adults were sorted into three groups: one that exercised and two others that acted as control groups by continuing with their normal sedentary lifestyles. The 12-week exercise program included stretching, walking, strength training, and dancing. Measures of intelligence as well as physiological factors such as heart rate and weight were taken before and after the program (*Geriatrics*, 1986). Those that saw improvements in their weight and heart rate also saw improvements in their cognitive abilities too, notably in skills generally associated with executive processing such as time management, organization and task-delegation. (*Geriatrics*, 1986).

Randomized intervention studies tested the link between fitness and improved cognitive ability in older adults between 65 and 85. Cognition was tested before and after participation in an exercise regime that lasted in a range of a few weeks to several years (Hillman, et al. 2008). One particular study randomly sorted its participants into two groups: one that performed a 10-week aerobic program and another control group that did not exercise during the trial (Hillman, et al. 2008). The adults were tested in a series of single and dual discrimination tasks involving auditory and visual stimuli. There was significant improvement in performance on the dual tasks by those on the aerobic program (Hillman, et al. 2008). This study is just one of many that suggest a link between aerobic exercise and cognitive improvement (e.g. *Geriatrics*, 1999).

In 1999, researchers at the University of Illinois at Urbana-Champaign also conducted a study observing the effects of exercise on cognition with elderly. The subjects ranged from 60 to 75 years of age and were either in a group of walkers or stretchers. The walkers improved their executive task functions, while the stretching group saw insignificant improvement (*Geriatrics*, 1999). This study in particular supports that there is significant importance for participating in aerobic exercise in order to improve cognition.

While these studies were impressive in their own regard, the research with human beings was observational in nature and lacked definitive results. Meanwhile, the animal-based research had clearly provided evidence in support of neuroplasticity, but many scientists were unwilling to apply the evidence gathered from other species to human beings. More advanced research techniques were necessary to convince most scientists that neuroplasticity in human beings was real.

<u>Advancements Through Technology</u>

It was not until Dr. Gage conducted an experiment at the turn of the 21st century that looked at slices of brain tissue in deceased cancer patients that the scientific community was willing to accept the notion of human adult neuroplasticity (Wildorf, 2001). Dr. Gage examined slices of the hippocampal region of deceased humans who had been injected with an indicator known as BrdU (Begley, 2009). The indicator would bind to new cells and was used to detect the formation of new cancer cells. Dr. Gage realized that BrdU could also accurately detect any new brain cells; if the indicator was considered reliable enough for diagnosing cancerous growths, it was certainly reliable enough to conclusively determine the existence of new brain cells. As Dr. Gage discovered and the neuroscience community had long rejected, there was clear evidence of neuroplasticity in adult human beings (Begley, 2009). The brain tissue samples were clearly marked with not one or two, but thousands of new brain cells; all which had formed in the last few years of life.

Using "recent advances in neuroimaging techniques" researchers started to discover more evidence to support the argument that "exercise leads to evident changes in brain structure and function" (Hillman, et al. 2008). These new technological advances allowed researchers to identify particular changes that quantified the neurophysiologic differences between those who are aerobically active and those who are not. One particular neuroimaging device, Electroencephalograms (EEG), have shown that aerobically active individuals have higher frequency theta, alpha, and beta spectral bands (Hillman, et al. 2008) which suggests the influence of physical exercise on cognitive function and operations. These bands' functioning at a higher frequency in those who exercise indicates a positive correlation occurs between brain function and exercise. The "variability in spectral frequency activation [of the bands] is related to… variations in the P3 component of the ERP [a technique used to collect raw EEG data]" (Hillman, et al. 2008). The P3 component, which is considered to be an objective measure of cognitive function, "has been found to be especially sensitive to changes in physical activity participation and aerobic fitness" (Hillman, et al. 2008). The research suggests that for people ranging from pre-adolescent children to older adults, there are larger amplitudes and shorter latencies in the P3 component for those who exercise more (Hillman, et al. 2008). This P3 component is generated by structures in the frontal and inferno-temporal lobes and the parietal and anterior cingulate cortexes: these areas of the brain are all responsible for processing stimuli and updating memory (Hillman, et al. 2008).

Other new technological innovations that have become instrumental in gathering evidence in support of neuroplasticity are the magnetic resonance imaging (MRI) and functional MRI (fMRI) machines. A study conducted by Dr. Colcombe and colleagues using MRI scans showed that higher levels of fitness correlated to larger volumes of the prefrontal and temporal lobes grey matter, and also to anterior cingulate cortex white matter (Hillman, et al. 2008). In a study conducted prior to Dr. Colcombe's research, the increase in grey and white matter volume within the brain has been shown to accurately forecast positive cognitive performance in older adults (Hillman, et al. 2008).

Using fMRI technology, researchers are able to measure the levels of cerebral blood volume (CBV) in the dentate gyrus, a portion of the hippocampus (Hillman, et al. 2008). This is particularly important because the hippocampal region is responsible for creating new neurons for the rest of the brain. The CBV levels were greater in participants who completed a three-month fitness program than those who were sedentary (Hillman, et al. 2008). The change in CBV levels is especially intriguing because of what is already known about the dentate gyrus - a study using mice found a link between increased CBV and neuroplasiticity in the dentate gyrus (Hillman, et al. 2008). While the link has yet to be concretely established in humans, the results are still promising and further research is being done.

<u>Brain Chemicals in Non-Human Studies</u>

Current research conducted on humans has been limited by the invasiveness of certain techniques, so while the results are more direct in human studies, further knowledge can be inferred through more obtrusive animal research. While brain imaging in humans has provided concrete support for the connection between physical exercise and cognition, neurochemical studies involving animal subjects have shown that exercise helps reinforce old neural connections while promoting new ones, which leads to a better ability to process information and store memories. A protein chemical called a "brain derived neurotrophic factor", or BDNF, which helps cells with growth and connection, is at the center of most neurochemical studies (Jozefowics, 2004). BDNF helps the brain convert everyday experiences into long-lasting habits, and raised BDNF in rats has been linked to everything from faster recovery from brain injuries to more efficient navigation of mazes. A study by Carl Cotman discovered that when rats exercised, they had BDNF levels twice as high as those that did not (Willdorf, 2001). A number of similar studies by Fernando Gomez-Pinilla and his colleagues have shown that rats only need minutes of swimming (Jozefowics, 2004) in order to increase BDNF levels. This is especially promising because exercise does not have to go on for hours, but merely minutes, to have cognitive benefits. While direct connections between BDNF in humans and physical exercise have not yet been made, Gomez-Pinilla recently launched a study with people who exercise regularly. Until the human study takes place, the current knowledge of physical exercise and its effects on cognitive function among human beings coupled with what has been discovered about the chemical BDNF must suffice.

Blood Flow and Stress Reduction

So far, the evidence presented has pointed toward the relationship of physical activity and cognition in broad ways. There are also many specific effects that exercise has on cognitive function. Two benefits of exercise are an increase in blood flow to the brain and the reduction of stress. Moderate exercise improves the ability of the heart to pump blood to all parts of the body, especially the brain (Amen, 2005). Without proper blood flow, the deep areas of the brain can suffer mini-strokes. Over time, these mini-strokes leave the brain in a state similar to those with Parkinson's disease (Amen, 2005). This is presumed to be a major reason why, generally, there is a drop in mental sharpness of those who do not exercise regularly as they age. Physical exercise also protects short-term memory structures in the temporal lobe region of the hippocampus from stress. The overproduction of cortisol from the adrenal gland is particularly damaging to cells in the hippocampus; in fact, Alzheimer's patients have much higher cortisol levels than the average aging person (Amen, 2005). Physical exercise combats this damaging process and offers protection for neurons that lasts approximately three days. This is why the recommended frequency of exercise is at least three days per week to help cognitive function.

Another mental benefit of physical exercise is its ability to increase production of glutathione, which is an antioxidant that protects cells from free radicals (Amen, 2005). These free radicals cause cell death by stripping vital proteins of electrons, therefore inactivating them. Brain cells are certainly no exception to this. As previously mentioned, physical exercise causes neurogenesis, but more specifically, the new neurons appear in the frontal lobes and the hippocampus (Begley, 2009). The glutathione production is particularly important because of these regions' susceptibility to age-deterioration.

Further Studies

Finally, there are certain studies that have looked at physical exercise and its affect on Alzheimer's disease and other forms of dementia. Generally, the first treatment prescribed for high blood pressure is physical exercise. The Honolulu Study of Aging found that high blood pressure during midlife years (from 40 to 60) significantly increases the risk of dementia (Amen, 2005). Another study conducted by Dr. D. Laurin and colleagues in Quebec examined the link between physical activity and dementia. A random sample of 9,008 men and women were evaluated once in 1991-1992 for a cognitive baseline (Amen, 2005). 6,434 of the subjects were cognitively normal when the data was first collected (Amen, 2005). Five years later, 4,615 subjects were re-evaluated; 3,894 subjects were considered healthy, 436 had mild impairment but no dementia and 285 were diagnosed with dementia (Amen, 2005). There was a much lower percentage of developing cognitive problems and/or dementia among those who exercised regularly (Amen, 2005). Finally, a study at Case Western Reserve University compared the amount of television watched daily, which relates to exercise levels, and the risk of developing Alzheimer's. People who watched at least two hours a day were twice as likely to be diagnosed with Alzheimer's (Willdorf, 2001). A reasonable conclusion for this study revolves around the fact that people only have a limited amount of free time during the day. If that time is spent watching television as opposed to exercising, these individuals likely miss out on the benefits of exercise.

Closing Remarks

While there is still more research to be done, the evidence at this point strongly suggests that physical exercise can positively impact the cognitive functions and overall structure of the brain. The neuroscience community has made great strides over the past half-century, but possibly none as profound as the acceptance of neuroplasticity in humans and the resulting positive correlation between exercise and improved brain function in support of this concept. While the acceptance of neuroplasticity in human beings has been slow at times, the consensus has certainly evolved. As a result, recent research has been aimed at promoting improved brain function and resisting the age-related mental diseases such as Alzheimer's through regular bouts of exercise. The research comes from both human and non-human studies alike and the information in support of a positive correlation continues to grow. As is the case in scientific inquiry some questions are yet to be decisively answered. What can be safely concluded is that with regular exercise that begins early enough in life and continues regularly, older adults are likely more resistant to a steep mental decline. Even those who are susceptible to diseases such as Alzheimer's can diligently prepare themselves in a manner that will, at the very least, slow the deterioration of cognitive function, and at the most, allow for a sustained higher cognitive state throughout old age.

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