

From PHI DELTA KAPPAN (<http://www.pdkintl.org/>)

## Physical Education Is Supported by Brain Research (Eric Jensen)

While many schools are reducing physical activity because of time constraints created by the No Child Left Behind Act, a large group of studies has linked physical activity with cognition. The researchers have come at the topic from a wide range of disciplines. Some are cognitive scientists or exercise physiologists. Other advocates are educational psychologists, neurobiologists, or physical educators. The applied research, which compares academic achievement between schools where kids have physical activity and those where they don't, also supports the hypothesis. Like six blind men describing different parts of an elephant, they are all addressing the same issue but from different viewpoints. They are all correct in revealing how physical experience affects the brain. Each of their viewpoints is valid, yet incomplete by itself.

Now let's add the neuroscience perspective. It reveals information that other disciplines cannot reveal. For example, we know that exercise is highly correlated with neurogenesis, the production of new brain cells. We know exercise upregulates a critical compound called brain-derived neurotrophic factor (BDNF). We also know that neurogenesis is correlated with improved learning and memory. In addition, neurogenesis appears to be inversely correlated with depression. While careless policy makers reduce physical activity, many administrators are unaware of the inverse correlations with adolescent depression. ***It's scary, but each year one in six teens makes plans for suicide, and roughly one in 12 teens attempts suicide. Yet there is considerable evidence that running can serve as an antidepressant.*** These data would suggest that educators might want to foster neurogenesis with physical education. But educators and policy makers can't see the new brain cells being produced. That's one reason to know the science, to show everyday, easy-to-influence school factors that regulate neurogenesis and, subsequently, cognition, memory, and mood. Those are the kinds of connections that should be made. They are not careless; there's little downside risk and much to gain.

To verify this hypothesis, we check the applied research to find out what happens to student achievement in schools where physical activity is either added or strengthened. The research in this arena is mixed because there are no broadly established protocols. For example, there are questions about when and how much physical activity is needed, what kind, and whether it should be voluntary. These are not trivial issues; our ***brains respond better to meaningful activities with appropriate duration and intensity over enough time to make changes. Voluntary activity is important, too. If the activity is forced, it is likely to generate distress, not cognitive or health benefits.*** But when the studies are well designed, there is support for physical activity in schools. So the interdisciplinary promotion of physical activity as a "brain-compatible" activity is well founded. Again, we see the brain involved in everything we do at school.

Thus a brain-based perspective strengthens the case for maintaining or enhancing physical activities in school. Was all of the research from the realm of neuroscience? No, it was from a wide range of sources. But every source still comes back to our brain. Is our brain enhanced or impaired by physical activity? The answer is clear: brains benefit from physical activity in many ways. The brain is involved in everything we do at school. How you measure it (basic science, cognitive science, psychology, applied research, sports research, neurochemistry, etc.) will still require the brain. While critics are trying to narrow the discussion of brain-based education to a "turf war" over where the science comes from, the bigger picture is simple: the brain is involved in everything we do at school. To ignore it is irresponsible.

[http://www.pdkintl.org/kappan/k\\_v89/k0802jen.htm](http://www.pdkintl.org/kappan/k_v89/k0802jen.htm)

is the link

## Buff and Brainy (All underlining is mine)

### Exercising the body can benefit the mind

#### Christen Brownlee

*This is part one of a two-part series on lifestyle and brain fitness. Part II: "Eat Smart," is available at*

<http://www.sciencenews.org/articles/20060304/bob8.asp>.

Anyone who frequents the local gym has probably noticed a cyclical pattern to attendance. Workout kings and queens exercise religiously throughout the year, but as swimsuit season approaches, a rash of new faces flocks to the facility. Every treadmill is taken, each elliptical machine is engaged, and without fail, there's a waiting line for a weight machine.

While exercise may be the path to looking great in a two-piece, everyone knows that it's also healthy for the body. It strengthens the heart and lungs, shores up thinning bones, and wards off a host of evils, including diabetes, heart disease, and stroke.

But what these newly inaugurated gym rats probably don't know is that besides buffing up their bodies for summer, they're also buffing up their brains. New research suggests that physical exercise encourages healthy brains to function at their optimum levels. Fitness prompts nerve cells to multiply, strengthens their connections, and protects them from harm. Benefits seem to extend to brains and nerves that are diseased or damaged. These findings could suggest new treatments for people with Alzheimer's disease, Parkinson's disease, and spinal cord injuries.

### Sweating to the oldies



*Just as physical exercise primes the body, researchers are finding that it also primes the mind. Exercise prompts brain cells to multiply, strengthens their connections, and boosts their resilience against damage and disease.*

Dean MacAdam

The cliché about a healthy mind residing in a healthy body has ancient roots. The famous quote of the same meaning, "*mens sana in corpore sano*" came from the Roman writer Juvenal in the early 100s A.D. And a century earlier, the philosopher Seneca was prescribing exercise as a way to achieve both physical and mental health.

But it wasn't until the early 1950s that reports that exercise conveys neurological benefits appeared in the scientific literature. These articles usually described what doctors had witnessed in their own practices, says neurobiologist Fernando Gómez-Pinilla of the University of California, Los Angeles. "This clinical literature described that exercise could be good for many different things," he says. The studies cited benefits ranging from alleviating depression and pain to regaining mobility in paralyzed limbs to maintaining good memory in old age.

However, for scientists who research how nerve cells work at a molecular level, such reports raise a bevy of questions. Gómez-Pinilla and other neurobiologists have aimed to fill this information gap by working with lab animals such as mice and rats—creatures that can be easily manipulated to sort out each one of an experiment's variables and that, unlike people, can be dissected in the end to get an insider's view of the brain.

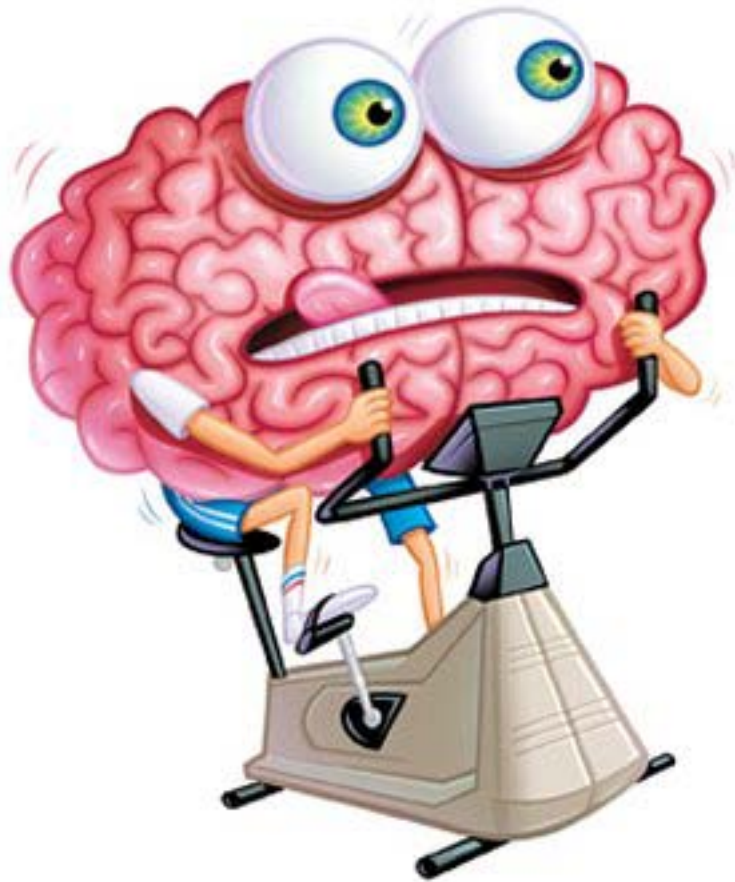
By the mid-1990s, researchers began to get answers. Preliminary studies indicated that when lab animals exercise, their nerve cells release chemicals called neurotrophic factors. These proteins buffer nerve cells against illness or injury, prompt them to grow and multiply, and strengthen each neuron's connection with other nerve cells.

Out of the variety of neurotrophic factors released during exercise, however, scientists found that one in particular stood out: brain-derived neurotrophic factor, or **BDNF**. *This protein seems to act as a ringleader, both prompting brain benefits on its own and triggering a cascade of other neural health-promoting chemicals to spring into action.*

"I think of BDNF as brain fertilizer. It's thrilling to see what it does to cells in culture," says **Carl Cotman**, a neuroscientist at the University of California, Irvine. ***Sprinkling a dilute solution of BDNF onto neurons in a lab dish makes the cells "grow like crazy," he adds. The cells sprout branches prolifically and extend them rapidly.***

## Let's get physical

Knowing what BDNF can do to neurons in the lab, researchers wondered whether the BDNF that exercising animals produce has similar effects on neurons in their brains. If so, could these physical effects translate into behavioral ones, making the animals learn quicker and better?



Dean MacAdam

In 1999, **Fred H. Gage of the Salk Institute in La Jolla, Calif., and his colleagues, including Salk's Henriette Van Praag**, began exploring these questions. They studied two groups of healthy mice housed individually in cages that were identical except for one detail: One group of mice had running wheels.

"The mice just love [the wheel]. They run on it as soon as you put it in their cages," says Van Praag. "If you let them run as much as they want, they run all night long."

Over the next several weeks, the researchers kept track as the runners voluntarily racked up an average of 4 to 5 kilometers on their wheels every night. The scientists then tested whether the groups differed in how quickly each mouse solved a popular learning test known as the **Morris water maze**.

Although both groups of mice swam at about the same speed, Gage and his colleagues noticed that the **runners learned the location of a platform**

***hidden under the maze's opaque water significantly sooner*** than their less-fit counterparts did.

Dissections showed that the ***runners had about twice as many new brain neurons*** as the sedentary mice did. When the researchers tested individual neurons isolated from both groups, they discovered that neurons taken from the runners showed greater signs of strengthened connections and cellular learning.

In a related study published in **2004**, **Gage's** team teased out the molecular factors responsible for the behavioral effects that come with exercise. The researchers provided a group of rats with running wheels and compared them with rats without access to the wheels. On average, the runners voluntarily racked up an astounding 48 km per day over the next several weeks.

When they dissected the rats' brains, Gage's team found changes similar to those that they'd seen in the previous study's mice: ***The runners had more new neurons and stronger connectivity, which is evidence of learning, than did the rats that didn't have running wheels.*** After examining the messenger RNA of both groups, an indicator of gene expression, the researchers found that the running rats had consistently higher activity in the gene that codes for BDNF than the nonrunners did.

Gómez-Pinilla and his colleagues added more evidence that BDNF is a primary source for the behavioral benefits of exercise. Like Gage's group, **Gómez-Pinilla's** team worked with rats that were either sedentary or had access to a running wheel. After a week, some members of each group began receiving daily injections of a drug that blocked the action of BDNF. The rest of the animals were injected daily for several days with a chemical called cytochrome-C, which isn't known to cause any physical or behavioral effects.

***The researchers then tested all the animals on the Morris water maze. While runners receiving cytochrome-C excelled at the test, runners that received the chemical that blocked BDNF performed only as well as the sedentary mice*** did. Performance by the nonrunners was about the same, regardless of which injection they received. *"If we block the action of BDNF, we block learning and memory," concludes Gómez-Pinilla.*

## **Keep on moving**

With mounting evidence of what exercise and its associated BDNF can do for healthy animals, researchers speculated that a similar mechanism could benefit animals and people stricken with neurological disease or injury. For example, in the **April 27, 2005 *Journal of Neuroscience***, **Cotman** and his colleagues suggested that exercise could slow the progression of Alzheimer's disease.

In the study, Cotman's team worked with mice that were genetically predisposed to develop an Alzheimer's-like disease. When they're a few weeks old—that's young adulthood in mice—the rodents' brains start accumulating a protein known as beta-amyloid. In the brains of people with Alzheimer's, this protein surges to form thick plaques that are one of the hallmarks of the disease.

As in other exercise-related studies, Cotman housed Alzheimer's-prone mice individually in cages, some of which were equipped with running wheels. At the start of the experiment, the animals were around 1 month old. Alzheimer's-like symptoms "had barely started by then," says Cotman.

After 5 months, the researchers tested the animals in the Morris water maze. As in the earlier studies, the ***exercisers fared significantly better on that memory test than the sedentary mice did.***



Dean MacAdam

However, in the "really exciting" part of the study, says Cotman, he and his colleagues dissected the animals' brains at 6 months of age to measure the ***beta-amyloid***. They were surprised to find about ***half as much accumulation of the substance in the runners as in the nonrunners.***

Cotman says that his team hasn't figured out how exercise reduces the buildup of amyloid-beta. But regardless of the mechanism, he notes that his results suggest that physical activity could eventually fight early Alzheimer's disease.

Exercise also shows promise in preventing Parkinson's-like symptoms from developing in animal models of that disease.

Surveys of lifestyle and health have suggested that ***people who exercise moderately, such as walking an hour each day, are less likely than others to develop Parkinson's disease.*** For the past 5 years, Michael Zigmond of the University of Pittsburgh and his colleagues have been experimenting with rats to explain this preventive effect.

In one study, the researchers forced healthy rats to exercise on a treadmill daily for a week. They then injected the animals with a chemical called 6-hydroxydopamine, which selectively kills dopamine-producing neurons. These cells also die in Parkinson's disease patients.

After several days, Zigmond's team examined the animals' brains. Compared with rats that received 6-hydroxydopamine but hadn't worked out on the treadmill, the exercisers lost fewer dopamine-producing neurons. Earlier studies had suggested that a protein called glial cell–derived neurotrophic factor (GDNF) protects dopamine-producing neurons in patients with Parkinson's disease and that neurons produce GDNF, just as they do BDNF, in response to exercise. So, Zigmond proposes that GDNF protected brain cells in the rats that exercised. He described his team's findings at the Society for Neuroscience meeting in October 2005 in Washington, D.C.

Researchers are also exploring physical activity as a way to treat neurological injuries, such as spinal cord damage. Although physical therapists have long helped patients regain some function by moving individual limbs affected by neurological damage, they have typically considered a patient with paralysis from the waist or neck down too damaged to rehabilitate.

"When you're told to go home and sit in a chair, your body doesn't get the feedback that comes from physical activity," says John McDonald, director of the International Center for Spinal Cord Injury at the Kennedy Krieger Institute in Baltimore. He developed exercise programs for Christopher Reeve as part of the late actor's therapy after his paralysis.

Without the neurotrophic factors produced in response to physical activity, McDonald hypothesizes, the nervous system fails to establish connections between damaged neurons and grow new ones.

To alleviate this problem, McDonald and his colleagues came up with a way for people with extensive paralysis to exercise. The researchers started with exercise bikes that had been equipped with electrodes that stimulate a patient's muscles to pedal. Heavy versions of these electrical-stimulation bikes had been used in physical therapy years ago, but their expense and inconvenience had made them fall out of favor. McDonald worked with the bikes' manufacturer to design models light enough for patients to use at home.

In a recent study, 24 people who had been paralyzed for an average of 5 years used the special bikes three times a week. Another 24 participants only stretched. After 2 years, 40 percent of the exercisers had regained some motor function, compared with only 4 percent of the other patients.

More research could eventually boost the bikes and similar assisted-movement equipment to become standard therapy for spinal cord injuries, says McDonald.

**Long may you run**

While evidence is soaring for exercise's brain benefits, physical fitness in the United States is plummeting. According to a report issued recently by the **Centers for Disease Control and Prevention, almost one-fifth of people 18 and over exercise for less than 10 minutes a week.** Only 46 percent of adults performed the recommended 30 minutes or more of brisk walking or other moderate exercise 5 days a week.

Whereas public health experts worry about the effects of a sedentary lifestyle on rates of heart disease, diabetes, and other health problems, Gómez-Pinilla is concerned that a lack of physical exercise could also foretell a wave of decreasing brain health for the United States.



Dean MacAdam

"Locomotion played a very important role in evolution. Animals had to move to find food and run away from predators. Exercise had a direct action on brain regions related to cognition," he says. "Normally, when two functions evolve in this way, you can't separate them."

But it's never too late to pick up an exercise program, according to psychologist David Albeck of the University of Colorado at Denver. Sedentary middle-aged and **elderly rats placed on a walking program showed improvements in learning and memory**, compared with sedentary rats of the same age, Albeck's team reported at the 2005 Society for Neuroscience meeting.

Furthermore, memory tests given to 1,740 people over 65 during a 6-year project have **linked moderate exercise to reduced risk of dementia**. These results were published in the **Jan. 17 Annals of Internal Medicine** by a Seattle research team.

That's yet another piece of good news for the pre-swimsuit season rush of exercisers that will appear, like clockwork, at gyms across the country. For these new gym rats, starting to exercise is a smart move, says Zigmond, but the smartest move will be to stick with exercising for years to come.

"If somebody were to stop me in the street and ask me what to do, I wouldn't have any problem telling them to exercise," he says. "There are lots of reasons to exercise, and virtually no reason not to."

For more than a century, medical science firmly believed that our brain could not repair itself and that we were born with all the brain cells we would ever have. That belief has changed. Over the last 20 years, research has shown that neurogenesis, the creation of new brain cells, actually occurs in the adult human. Currently, work is shifting to find out where neurogenesis happens, how it happens, why it happens, and, more importantly, how it might help the brain heal itself.

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We've been taught for generations that the adult brain doesn't create new brain cells. The cells you have at birth are about all you'll ever have, and a neuron lost is lost forever. Now, medical science has learned a different lesson.

Research over the last decade has produced growing evidence that the adult human brain creates new neurons, a process known as neurogenesis. Recent findings show that many of these new neurons survive and integrate themselves into the working brain, suggesting the potential for a self-healing brain. If researchers can harness and enhance neurogenesis, it could lead to improved treatments for many disorders, diseases, or damage -- from Alzheimer's and epilepsy to stroke and traumatic brain injury -- and it can help keep our minds and memories sharp.

Already research has:

- Identified areas of the brain where neurogenesis is evident.
- Discovered the processes that may promote or inhibit neurogenesis.
- Offered a glimpse of how new neurons may assimilate into the working brain.

What began with the song of a small bird has changed an entire paradigm in neuroscience. About 20 years ago, research on the ability of adult songbirds to learn new songs showed that their brains created new cells and that these neurons helped them form memories of the new songs. This opened up debate on whether the same process occurred in humans. Subsequent research confirmed human neurogenesis, and now questions revolve around the extent that neurogenesis occurs, where it occurs, and the function new neurons perform

in the working brain.

In order to understand neurogenesis better, it helps to understand that not all new neurons live very long after birth. In fact, more die than survive, which may be one reason it took so long for researchers to recognize neurogenesis in the adult brain.

*To live and become part of the working brain, a new neuron needs not only support from neighboring glial cells and nutrients from blood, but also, and more important, connections with other neurons. Without these connections, neurons wither and die. (Learning must occur)*

Research to date suggests that the most active area of neurogenesis is the hippocampus, a region deep within the brain involved in learning and memory. **Research has shown that thousands of new cells are produced in the hippocampus each day**, although many die within weeks of their birth.

\*\*Recent animal studies have shown a correlation between learning and new neurons surviving in the hippocampus. After teaching rodents a variety of tasks that engaged a range of brain areas, scientists found that, generally, the more the animal learned, the more neurons survived in the hippocampus. Cells that were born before the learning experience were more likely to survive to become neurons, but only if the animals actually learned. The increase in survival occurred with tasks that depended on the hippocampus as well as those that required significant effort to learn.

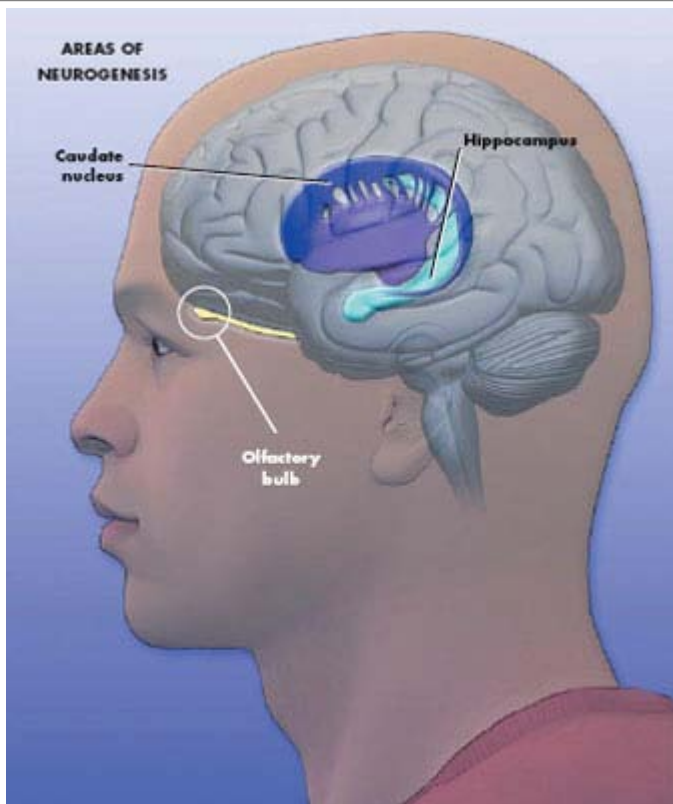
Everybody knows that exercise is good for your heart, but in recent years, compelling evidence has shown that exercise is also good for your brain. **Experiments have found that mice that used a running wheel had about twice as many new hippocampal neurons as mice that didn't exercise.** Learning may still be necessary to preserve them, however.

Other research has found that **beta-endorphin**, a mood-elevating chemical produced by the hypothalamus and the pituitary gland, may play a role in the effects of exercise on the brain. Mice producing beta-endorphin and exercising showed an increase in the hippocampus in both the number of newborn cells and the rate at which those cells survived. However, mice that could not produce beta-endorphin but were still allowed to exercise showed no change in neurogenesis.

Recent experiments using antidepressant therapy found that it stimulates

neurogenesis in adult animals. On the other hand, stress seems to work against the production of new cells.

A key question for researchers now is what do these new neurons do once they survive and become part of the working brain. Do they merely replace old neurons, or do they form entirely new circuits? Are they responsible for new memories? Some very recent studies suggest that the strength of a memory can relate to how many new neurons remain in the brain after learning. These new insights are opening up many exciting avenues of research for scientists as they increase their understanding of how our brains work.



Although scientists still debate the extent and purpose of neurogenesis in the adult brain, research has identified certain areas of the brain where it is most evident. These areas include the hippocampus, caudate nucleus, and olfactory bulb.

For additional information, check out:

*The Journal of Neuroscience*. 2007 Mar; 27(13): 3252-3259. Experience-Specific

Functional Modification of the Dentate Gyrus through Adult Neurogenesis: A Critical Period during an Immature Stage. Tashiro A, Makino H, Gage FH.

*The Journal of Neuroscience*. 2006 Jan; 26(2):609-621. Neurogenesis in the Caudate Nucleus of the Adult Rabbit. Luzzati F, De Marchis S, Fasolo A, and Peretto P.

*The Journal of Neuroscience*. 2006 Mar; 27(11): 2734-43. Acute Psychosocial Stress Reduces Cell Survival in Adult Hippocampal Neurogenesis without Altering Proliferation. Thomas RM, Hotsenpiller G, Peterson DA.

*The Journal of Neuroscience*. 2006 May; 26(22):5888 -5893. Long-Term Potentiation Enhances Neurogenesis in the Adult Dentate Gyrus. Bruel-Jungerman E, Davis S, Rampon C, and Laroche S.

*Proc Natl Acad Sci USA*. 1999 May; 96: 5768-5773. Continuation of neurogenesis in the hippocampus of the adult macaque monkey. Kornack DR, Rakic P.

*Sci STKE*. 2003 Aug; (195):318. Antidepressants and Hippocampal Neurogenesis. Santarelli L, Saxe M, Gross A, Surget A, Battaglia F, Dulawa S, Weisstaub N, Lee J, Duman R, Arancio O, Belzung, Hen R.

### **Brain-related benefits of exercise:**

- impacts children's frontal lobe, a primary brain area for mental concentration, planning, and decision-making.
- improves short-term memory, creativity, and reaction time.
- gives the brain its needed nutrients (glucose).
- balances brain chemicals, hormones, electricity, and system functions.
- promotes brain cell regeneration and growth.
- releases endorphins, the class of neurotransmitters that relax us into a state of cortical alertness.
- reduces the symptoms of depression.
- raises levels of glucose, serotonin, epinephrine, and dopamine, chemicals that at elevated levels are known to inhibit hunger and balance behavior.
- Increases the speed that subjects processed information, memory span, and problem solving.
- blood flow is increased in all parts of the brain making it more alert and energized for stronger, more cohesive learning.
- assists in memory.
- stimulates the productions of neurotrophins that increase the number of synaptic connections.

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### **California study linking fitness levels and academic achievement:**

SACRAMENTO — State Superintendent of Public Instruction Delaine Eastin today announced that the results of a recent study conducted by the California Department of Education (CDE) show a distinct relationship between academic achievement and the physical fitness of California's public school students.

"This statewide study provides compelling evidence that the physical well-being of students has a direct impact on their ability to achieve academically," said Eastin. "We now have the proof we've been looking for: students achieve best when they are physically fit. Thousands of years ago, the Greeks understood the importance of improving spirit, mind, and body. The research presented here validates their philosophic approach with scientific validation."

Number of participants:

353,000 fifth graders  
322,000 seventh graders  
279,000 ninth graders

- The height of each bar shows the average (median) SAT-9 national percentile rank of those students with a particular fitness score.

- Higher academic achievement is associated with higher levels of fitness in grade 5, 7, & 9.
- Students in grade 5, 7, & 9 who meet minimum fitness levels in three or more physical fitness areas show the greatest gains in academic achievement.
- The relationship between academic achievement and fitness in grade 5, 7, & 9 was greater in mathematics than in reading, particularly at high fitness levels.

The test that was used, *Fitnessgram*, uses criterion-referenced standards to evaluate fitness. These standards represent a level of fitness that offers some degree of protection against diseases that result from sedentary living. Achievement of the fitness standards is based upon a test score falling in the Healthy Fitness Zone (HFZ). Each of the six tasks measures a different aspect of fitness, and the HFZ represent minimal levels of satisfactory achievement on the tasks.

**Data Summary from California Study:**

**2001 Grade 5 SAT 9 and Physical Fitness**

<b>Number of Fitness Standards Achieved</b>	<b>SAT 9 Percentile Reading</b>	<b>SAT 9 Percentile Mathematics</b>
1	29	36
2	32	40
3	36	45
4	40	50
5	46	58
6	55	71

### 2001 Grade 7 SAT 9 and Physical Fitness

<b>Number of Fitness Standards Achieved</b>	<b>SAT 9 Percentile Reading</b>	<b>SAT 9 Percentile Mathematics</b>
1	26	28
2	31	32
3	34	36
4	41	44
5	50	54
6	60	66

### 2001 Grade 9 SAT 9 and Physical Fitness

<b>Number of Fitness Standards Achieved</b>	<b>SAT 9 Percentile Reading</b>	<b>SAT 9 Percentile Mathematics</b>
1	21	35
2	24	38
3	28	43
4	31	51
5	37	58
6	45	67

## **The Effects of Daily Exercise and Nutrition**

From Edutopia (Dec/Jan 2006) from Fighting for Fitness [cover story] page 34:  
by Evantheia Schibsted

“Increasingly, educators are finding that a healthy lifestyle promotes higher academic performance. Two years ago, Anthony Elementary School, a K-5 school in Leavenworth, Kansas, implemented a health-oriented program for its 350 students, which requires that they exercise, eat more nutritious lunches, and take two vitamin mineral supplements daily.

Before the program, Anthony was ranked ninth in standardized math tests and tenth in English exams in a district of ten schools. One year into the health program, the school’s test scores rose to first in math and second in English. Student behavior also improved: Office referrals plummeted from 438 incidents in one year to 18. Additionally the number of students who met the Presidential Fitness Standards rose from 3 to 40 in the first year.”

### **Why movement is critical to learning:**

**Increased oxygen to the brain** – The brain relies on blood to nourish it. The more blood that is available to the brain, the better able the brain is to think, reason, problem-solve and create. Aerobic activity increases and enhances the body’s ability to transport blood (carrying oxygen) to the brain. Regular aerobic exercise is one of the best things to do for your brain.

**More blood capillaries develop** – With increase aerobic conditioning; the brain develops more blood capillaries. These capillaries branch out into the brain creating “blood flowing” pathways to more regions of the brain. This will provide the brain with increasing levels of oxygen and nutrients, which enables the brain to perform better. Regular aerobic exercise is one of the best things to do for your brain.

**Movement develops more neural connections** – The brain relies on neural connections (connections made between nerve cells) to send and receive information. This transmission of information is the brain’s ability to think, learn, create, problem solve, etc. The more neural connections made the smarter the brain becomes in regards to processing information. When learning is linked to movement, more neural connections are made and greater learning takes place. Adding movement “anchors” the learning into the brain better than if no movement is used. If we want children to learn, we need to give them

opportunity to move, touch, feel, and experience things in a hands-on approach. Learning is doing.

**Regulates neurotransmitter** - Exercise and physical activity helps release “brain-derived neurotrophic factors” (BDNF). BDNF is a natural substance within the brain that increases the ability of the neurons to send messages to each other. The more the BDNF floating around, the easier it is for the brain to process information. Exercise is the key in helping the brain produce BDNF.

**Reduce Stress** – Stress is one of the greatest influences on how students learn. Since many students are faced with different types of stressors (embarrassment, deadlines, expectation, etc.) daily, exercise is key in enabling the brain to regulate itself and deal with stress. With high levels of stress causes the adrenal glands to secrete cortisol into the blood stream. The production of cortisol causes the body to depress the immune system, tense muscles, increase blood pressure and form blood clots. Regular exercise helps to regulate the production of cortisol allowing the brain to function properly. Exercise reduces the very stress that inhibits the brains ability to function properly.

It is not hard to figure that movement, physical activity, and hands-on learning are essential to optimal brain function. The more one knows about the brain, how it works, and what affects it the more obvious it becomes that physical education is an indispensable part of student’s education. Physical Education is essential to learning.

Resource:

PE Resources – Brain-Compatible Physical Education Booklet: Play with the Brain. PE Publishing Company, 237 Beau Tree Drive, Wilmington DE. 19810. 2001

## History of Research leading to the Discovery that Exercise Enhances Learning

**Hebb (1945):** “use-dependent plasticity”: synapses rearrange themselves under the stimulus of learning – Hebb took lab rats home and let this children play with them. He found they excelled on learning tests compared to caged rats.

**Berkeley psychologists (1960’s)** test the use dependency theory by outfitting cages with wheels, toys, obstacles and created a social environment. Result: those rats did better on learning tasks and their brains *weighed more*.

**Harvard** study showed the reverse was also true: sensory deprivation can shrink the brain  
Cats with one eye sewn shut had a smaller visual cortex

**Greenough (1970’s)** University of Illinois found environmental enrichment (social contact, exercise, learning stimulation) caused new dendrite growth with thicker myelin sheaths which allow them to not just have more connections or pathways but more efficient firing of signals [This happens as a results of BDNF]

**1998 Neurogenesis Eriksson & Gage** study on cancer patients found that when injected with a dye that appears in proliferating cells it was found in the hippocampus

--**Gage** discovers that by adding *only* a running wheel to the rats’ cage increases the number of new brain cells being born

**Van Praag** discovered mice with nightly runs on an exercise wheel developed a better memory and had twice the number of new stem cells in the hippocampus than sedentary mice –

Experiment: mice were given a swim in an opaque water filled pool and then later dropped back in. The pool had a submerged, concealed platform by which the mice could find safety. The fit mice remembered the escape route more quickly.

Brain cells that aren’t used die / Rats (& people) with a larger pool of brain cells have more cells survive

**“Exercise spawns neurons, and the stimulation of environmental enrichment helps those cells survive.” Ratey p49** Exercise creates the neurons, learning fills them

**Elizabeth Gould** [1999] first showed neurogenesis occurs in primates and thereby in humans

*\*\*Researchers have mice and rats run because it “massively increases neurogenesis” and they are studying neurogenesis NOT how to enrich the quality of rats’ health. This is similar to educators who see aerobic fitness not as a way to better the health of today’s students but rather as a way to increase neurogenesis and thereby learning/test scores.*

BDNF [brain derived neurotrophic factor] strengthens myelin sheath and dendrite growth support the survival of existing neurons and encourage the growth and differentiation of new neurons and [synapses](#). In the brain, it is active in the [hippocampus](#), [cortex](#), and basal [forebrain](#)—areas vital to learning, memory, and higher thinking. BDNF was the second neurotrophic factor to be characterized after nerve growth factor ([NGF](#)).

IGF-1 [Insulin-like growth factor] works with insulin to deliver glucose (only source of energy for the brain) to the cells (BDNF helps brain increase uptake of IGF-1 stimulator of cell growth

VEGF [vascular endothelial growth factor] factor in increasing capillary growth

FGF-2 [Fibroblast growth factor]

Astrocytes: cells that clean up synapses after transmissions (perhaps a plaque reducer?)

## Physiological Basis of Exercise and Learning

- 1] Hebb (1945) Use dependent plasticity – handled rats perform better on learning tasks
- 2] U of Cal Berkeley psychologists – found rats in environmentally rich cages did better on learning tasks – THEIR BRAINS WEIGHED MORE (researched that spawned Head Start)
- 3] Greenough (1970's @ U of Ill) found environmental enrichment caused new dendrite growth with thicker myelin sheaths which allow them to not just have more connections or pathways but more efficient firing of signals
- 4] Cotman (1995) found BDNF in the hippocampus of mice
- 4b] Cotman (?) Study on aging found education, self efficacy, and exercise common in subjects whose brains held up best
- 4c] Cotman (2005) BDNF levels in mice brains in direct proportion to fitness levels (4 grps: inactive, 2, 4, 7 nights on a running wheel)
- 5] Eriksson & Gage (1998) Neurogenesis: study on cancer patients found that when injected with a dye that appears in proliferating cells it was found in the hippocampus
- 6] Hannaford (1995) Activity stimulates the growth of developing brains by producing NGF (nerve growth factor) [Howard 2000] [Jensen & Dabney 2000] [Jensen 2000a].
- 6] Gage discovers that by adding *only* a running wheel to the rats' cage increases the number of new brain cells being born
- 7] Van Praag discovered mice with nightly runs on an exercise wheel developed a better memory and had twice the number of new stem cells in the hippocampus than sedentary mice  
–Experiment: mice were given a swim in an opaque water filled pool and then later dropped back in. The pool had a submerged, concealed platform by which the mice could find safety. The fit mice remembered the escape route more quickly.
- 8] Greenough found fit rats who had learned complex motor skills had a 35% increase in BDNF in the cerebellum compared with running rats who had a 0% increase

## **Studies on the relationship of fitness to academic performance**

- 1] CDE (2001) showed a direct correlation between fitness and SAT scores
  - Fit students scored twice as well as unfit students on the SAT
  - 9<sup>th</sup> graders w 6/6 passes of fitness components scored at 67 %tile in math and 45<sup>th</sup> in reading
  - 1/6 passes scored 35<sup>th</sup> in math and 21<sup>st</sup> in reading
- 2] Hillman (U of Ill) found the same correlation in 216 3<sup>rd</sup> and 5<sup>th</sup> graders
  - Using EEG scans found fit kids had more neurons active during tasks
  - More fit students responded better to mistakes

## **Studies in Academic Settings**

- 1] Naperville Central, Ill HS: Learning Readiness PE
- 2] Titusville, PA:
  - Went to daily PE adding 10 min to school day while shaving time off academic classes
  - Reading Scores: below state average to + 17% above
  - Math scores: below state average to +18% above
  - No fistfights since 2000
- 3] Anthony Elementary, Leavenworth, KS: Instituted daily exercise, improved lunch offerings, and daily vitamin supplement:
  - 9<sup>th</sup> of 10 in math to 1<sup>st</sup>
  - 10<sup>th</sup> in reading to 2<sup>nd</sup>
- 4] CDE study of 1,000,000 found a direct correlation between performance on the Stanford Achievement Test and the number of Fitnessgram test components passed

"Aerobic exercise training showed dose-response benefits on executive function (decision-making) and possibly math achievement, in overweight children," the researchers wrote in an abstract presented this week at The Obesity Society's annual scientific meeting in New Orleans. "Regular exercise may be a simple, important method of enhancing children's cognitive and academic development. These results may persuade educators to implement vigorous physical activity curricula during a childhood obesity epidemic." the researchers concluded.

Before the program, Anthony was ranked ninth in standardized math tests and tenth in English exams in a district of ten schools. One year into the health program, the school's test scores rose to first in math and second in English. Student behavior also improved: Office referrals plummeted from 438 incidents in one year to 18. Additionally the number of students who met the Presidential Fitness Standards rose from 3 to 40 in the first year."

New research suggests that physical exercise encourages healthy brains to function at their optimum levels. Fitness prompts nerve cells to multiply, strengthens their connections, and protects them from harm. Benefits seem to extend to brains and nerves that are diseased or damaged. These findings could suggest new treatments for people with Alzheimer's disease, Parkinson's disease, and spinal cord injuries.