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EXERCISE KEEPS THE BRAIN HEALTHY!

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YOUNG REVIEWERS:

GABRIEL
AGE: 9

LICEO STATALE M. G. AGNESI
AGES: 14–15

Did you know that exercise may help your brain work better? Scientists are studying how kids' brains respond to exercise and how physical activity may help kids learn better in school. Using equipment that can help them to see the structure and function of the brain, scientists can measure and record what the brain is doing while kids engage in tasks that require attention and memory, or while they are just resting. Physical fitness and physical activity can help kids' brains function better, help them to stay focused in school, and help them do well on tests. In this article, we explore research aimed at how being physically fit and participating in physical activities may not only benefit kids' bodies, but also benefit their brains and improve skills like attention, memory, and learning.

INTRODUCTION

You have probably heard that being physically active can make you stronger, faster, and generally healthier. However, does it surprise you to learn that physical activity (PA) can also make you smarter and help you do better in school? Recess, physical education, and playing sports helps more than just our bodies: it benefits our brains, too! Over the past several decades, scientists have learned a lot about how PA can improve our brains.

Much of the earliest research on PA and the brain was done in animals, mostly rats and mice. Scientists found that when rodents ran on a running wheel each day for several weeks, their brains got healthier and they had better memory for learning how to complete a maze. The rodents' brains were healthier because they grew new neurons (brain cells that send information throughout the brain and body), developed new connections between neurons, and improved the brain's blood supply [1]. Recently, there have been studies of how PA affects humans, from children to senior citizens, including people with medical conditions such as attention deficit hyperactivity disorder, Parkinson's disease, autism spectrum disorder, Alzheimer's disease, and many others.

PA is defined as any bodily movement that uses more energy than the body uses at rest. We focus on aerobic fitness, which refers to how well the lungs and heart pump oxygen and blood through the body. We measure physical fitness and PA in the lab, using high-tech equipment and special sensors. To measure fitness, kids run on a treadmill that keeps getting steeper, while wearing a mask that measures how much air goes in and out of their lungs with every single breath (Figure 1).

Figure 1

A 14-year-old performing an exercise test on a treadmill to measure aerobic fitness. The blue mask measures how much oxygen the child's body uses while exercising (Photo credit: Alyssa Stone/Northeastern University).

EXECUTIVE FUNCTIONS

Important brain functions that we use every day that help us concentrate and pay attention. They include inhibition, working memory, and cognitive flexibility.

INHIBITION

This is an executive function that allows people to concentrate and pay attention.

WORKING MEMORY

This is an executive function that helps people process and remember things.

COGNITIVE FLEXIBILITY

This is an executive function that helps people shift their attention based on environmental demands and perform multiple tasks at once.

We also measure how many times their hearts beat in 1 min. The kids' hearts beat faster as they continue running on the treadmill. Kids who are more fit use more oxygen while they are exercising.

Research suggests that kids who are more physically active and more physically fit score better on standardized tests of math and reading [2, 3]. Fit kids also have better attention and memory. For example, they are better able to remember names and locations on a map compared to kids who are less physically fit. Kids who are more fit perform better on tests that measure a specific type of thinking known as **executive functions**. Executive functions help us to concentrate and pay attention (this is called **inhibition**), remember things (called **working memory**), and perform multiple tasks at once (called **cognitive flexibility**). You do these activities every day, especially in school! You use inhibition when you ignore other classmates who are being distracting and focus on your teacher instead. If you are multiplying numbers in your head or being creative, you are using working memory. Cognitive flexibility is sometimes called multi-tasking, like when you ride a bike and also watch out for cars and people in your path. Executive functions are associated with an area in the front part of the brain known as the prefrontal cortex, which is still developing in kids. In fact, executive functions are not mature until college, but being physically active helps kids' executive functions while their brains are still developing [4].

EXERCISE AND THE ELECTRICAL ACTIVITY OF THE BRAIN

ELECTROENCEPHALOGRAPHY

A technique that records electrical brain activity. Small sensors on the scalp pick up the electrical signals produced by the brain to create brain waves.

In the laboratory, scientists can study how the brain's structure and function change because of PA and fitness. One way to do this is by measuring the electrical activity in the brain using a technique called **electroencephalography** (EEG). The child being studied wears a special cap that looks like a swimming cap, with many sensors placed in it. The sensors measure the electrical activity happening in the brain. EEG caps are very safe for kids and have no side effects. Sometimes scientists measure what the brain is doing while the child is resting, and other times they measure what the brain is doing while the child completes tasks that require attention or memory. Kids who are more fit are better at blocking out distractions and have more efficient brain activity. But, the good news is that it may only take 20 min of walking to see improvements in brain activity [5]. Experiments have shown that, after kids walk on a treadmill for 20 min at a pace that makes them sweat but allows them to talk easily, they are better able to temporarily pay attention and ignore distractions. After walking, kids' brain activity is more efficient and faster than it is after sitting for 20 min (Figure 2). Importantly, after an entire school year with extra PA, kids were physically healthier, their brain activity was better, and they were better able to ignore distractions and pay attention [6].

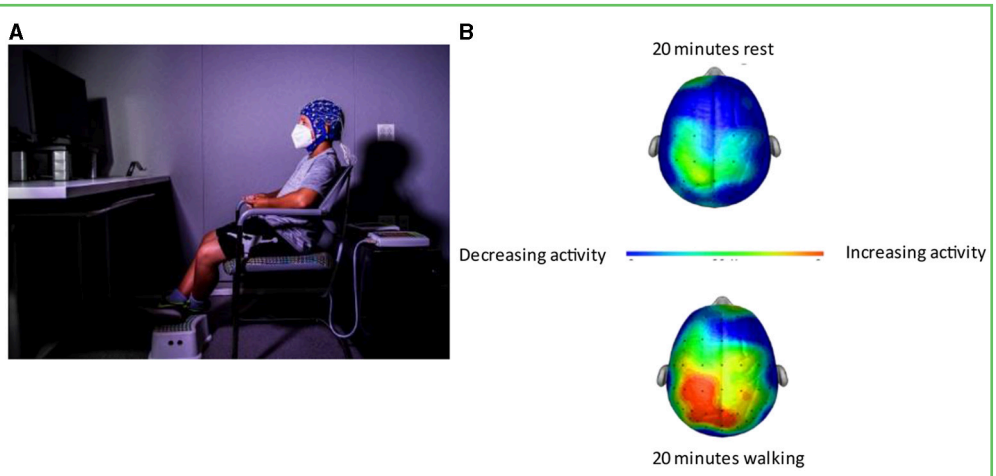

Figure 2

Figure 2

(A) Child wearing an EEG cap while completing a thinking task on the computer. The EEG cap contains 64 sensors that measure the electrical activity of the brain (Photo credit: Alyssa Stone/Northeastern University). **(B)** After either 20 min of rest or 20 min of walking, the child's brain activity was measured while they performed a challenging mental task. You can see that, after walking for 20 min, there was much more activity in the brain [4] (Image credit: Alyssa Stone/Northeastern University).

MAGNETIC RESONANCE IMAGING (MRI)

A technique that uses a really strong magnet to look at brain structures.

HIPPOCAMPUS

An important brain structure that looks like a seahorse that is important for learning and memory.

FUNCTIONAL MAGNETIC RESONANCE IMAGING (fMRI)

This technique is similar to an MRI, but this looks at how the brain is working based on where oxygen is moving in the brain.

EXERCISE AND BRAIN STRUCTURE

Scientists can also measure brain structure and function using a technique called **magnetic resonance imaging (MRI)**. MRI machines are safe and painless for children if the children do not have any metal objects in their bodies, and kids are always safety checked before getting into an MRI scanner. Kids must stay very still in the MRI scanner, but sometimes they get to watch movies or engage in tasks of attention and memory. These machines, which look a bit like spaceships, have very strong magnets that make loud noises. The MRI machine lets scientists take many pictures of a kid's brain from multiple directions. These pictures allow scientists to measure the various structures in the brain.

Using MRI, scientists have found that a small but important area in the middle of the brain, called the **hippocampus**, is larger in kids who are more fit compared to kids who are less fit (Figure 3) [7]. The hippocampus looks like a seahorse and is important for learning and memory. A larger hippocampus has been associated with better memory. The hippocampus plays a special role in a type of memory called relational memory. This is the type of memory that helps you make connections, such as remembering a new student's name, along with what that student looks like and what you last talked to them about. It is important to keep the hippocampus healthy, and we can do so by staying physically active, eating a well-balanced diet, and getting adequate sleep.

EXERCISE AND BRAIN FUNCTION

MRI also allows scientists to study brain *function*, in which case it is called **functional magnetic resonance imaging (fMRI)**. fMRI lets scientists take pictures of children's brains while they are working on specific activities. The blood carries oxygen to the brain and the

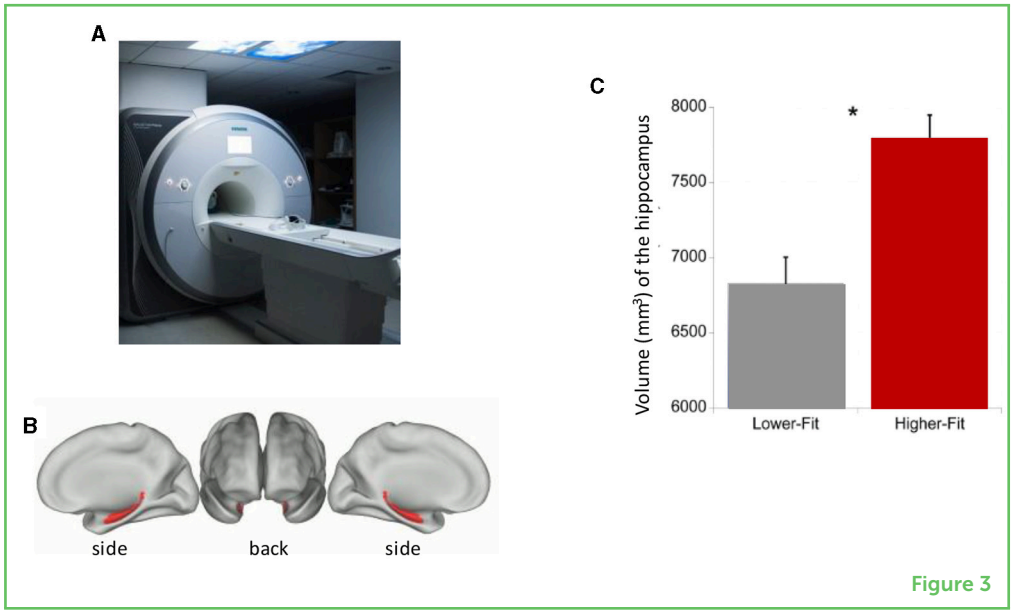

Figure 3

(A) An MRI scanner, used to measure brain structures (such as the hippocampus) and brain function. **(B)** These brain images show the location of the hippocampus, in red. **(C)** This graph shows that the hippocampi of children with higher levels of fitness were significantly larger than the hippocampi of children with lower levels of fitness [7] (Image credit: Northeastern University).

brain uses oxygen while doing activities. fMRI measures brain activity by measuring changes in blood flow (and thus oxygen flow) to the brain (for more information on fMRI, see this Frontiers for Young Minds article). So, fMRI helps scientists to see how separate regions of the brain communicate with each other when a person is resting, or when the person is performing a task such as remembering numbers or faces. In this case, higher fitness is related to better communication between the separate regions of the brain.

LET'S GET ACTIVE!

The good news is that we can improve how our brains function with PA! Doctors and scientists suggest that kids get at least 60 min of PA every day—the kind that makes your heart beat faster and makes you sweat! But more than 50% of kids do not get this much exercise. Why? Kids may not have a safe place to be active, or some of them many not have found an activity that they like. Other kids may feel embarrassed when learning a new activity or sport—so it is always good to cheer on others who are being active! Any activity that gets the heart pumping, like bicycling, swimming, or jogging, would be a good choice. Even walking is really good for the brain. It is also important to perform exercises that build muscle strength (like pushups or sit ups) and exercises that build strong bones (like jumping rope). Try to rotate between a few types of physical activity that you enjoy! Scientists are currently trying to figure out what types of sports and activities are best for the brain, and how to keep kids engaged and interested in physical activity.

When you talk to your parents and grandparents about PA, you can let them know that being physically active will help *their* brains stay

healthier, too—keeping their executive functions in shape as they age. Brain structures like the hippocampus are often smaller in older adults, like your grandparents, compared to when they were younger. However, after walking for an hour 3 days a week for 1 year, older adults had larger hippocampi, which led to better memory.

While being physically fit is important for your brain to operate at its best, there are many other important ways to build a healthy brain and body. For example, eating healthy foods like vegetables and playing musical instruments also benefit brain health. Getting enough sleep is important too, so your brain can rest and form memories, as well as pay better attention the next day. Scientists think these lifestyle activities that make kids' brains healthier are good for people of all ages—from your younger siblings to your grandparents. So, grab a friend or family member, go for a walk, and talk about all the ways we can keep our brains healthy!

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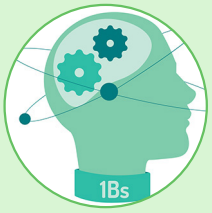
CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

GABRIEL, AGE: 9
Gabriel Garrigues is 9 and he is in fourth grade. He is interested in chemistry and he also likes to be a leader. For example, he likes organizing things and planning ahead. He also swims competitively. Finally, he wants to help stop climate change and make the world more clean.



LICEO STATALE M. G. AGNESI, AGES: 14–15
Hello there! That is us, a class of 29 students: 1°Bs of Liceo Scientifico Maria Gaetana Agnesi, in Italy. This year, we have taken part in many projects organized by our school and now we are happy to do this scientific project since it is different from the others and is definitely the best we have done so far. We enjoyed this activity a lot and we are looking forward to reading the final article!

AUTHORS

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Jennifer Watrous is a graduate student in the Department of Psychology at Oklahoma State University. During her undergraduate career at Suffolk University, she became interested in developmental psychology. While she was a member of the Center for Cognitive and Brain Health, she worked on research funded by the National Institutes of Health investigating children's brain health, with a focus on behavioral and emotional changes. During her leisure time, she likes discovering new places to eat and travel. Her future work will help children and young adults be healthier, both physically and mentally.

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Charles Hillman is a professor at Northeastern University, where he holds appointments in the Department of Psychology and the Department of Physical Therapy, Movement, and Rehabilitation Sciences. He is the associate director in the Center for Cognitive and Brain Health, and has published 300 journal articles, 13 book chapters, and edited one textbook. He served on the 2018 Physical Activity Guidelines for American's Scientific Advisory Committee. His work has been funded by the National Institutes of Health for the past 20 years, and he has been featured in the media including: CNN, National Public Radio, Newsweek, and the New York Times.

ARTHUR F. KRAMER
Art Kramer is a professor of psychology and director of the Center for Cognition and Brain Health at Northeastern University. In addition to studying the effects of exercise on brains and minds, he is also interested in how cognitive challenges such as new learning and diet can be used to enhance our brains. He has enjoyed a number of physical activities across his life, from running, hiking, skiing, mountain climbing, and playing a variety of racquet sports.