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Biology

Advanced

Unit 5: Energy, Exercise and Coordination

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Scientific Article for use with Question 7

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Scientific article for use with Question 7

How exercise boosts your brain

<https://www.newscientist.com/article/mg22029421-000-run-yourself-smarter-how-exercise-boosts-your-brain/> This article appeared in print under the headline "Faster body, faster mind" (NS)

Why choosing the right workout could fine-tune your brain

https://www.newscientist.com/article/2054777-why-choosing-the-right-workout-could-fine-tune-your-brain/

1. ANYONE hoping for a quiet doze during John Ratey's speech would have been disappointed. Addressing 1100 of the world's leading educators, he invited them to join him in a spot of exercise. "We ran in place for 20 seconds, then rested for 10 seconds, then repeated this four more times," says Ratey.

2. This might seem an odd approach for a psychiatrist speaking at an education conference. But Ratey, who is based at Harvard Medical School, knew that getting the crowd to limber up before his speech was in his own interests – it would make them more alert and might even help them retain more of what they were about to hear. "It got the whole group ready to listen," he says. It was also the perfect introduction for a keynote speech on the ways that we can all use our bodies to improve our minds.

3. It has long been accepted that exercise cuts the risk of getting heart disease, and recent studies suggest a raft of more general benefits, such as reducing the risk of certain types of cancer and even preventing the onset of type II diabetes. Now it seems that gym junkies can also expect a boost in brain power.

4. This is not just the vague glow of well-being that is suggested by sayings such as "a sound mind lives in a healthy body". Instead, Ratey and others are finding that fitness has a profound long-term influence on a wide range of cognitive abilities that shape your IQ. Physical activity seems to be important during childhood, powering the brain through the many changes that help us to mature into adulthood. But it may also play a role during our dotage, with a decline in fitness explaining why some people are more prone to dementia.

5. "It's a really amazing effect, and it makes this one of the most exciting areas in exercise physiology," says David Raichlen, a biological anthropologist at the University of Arizona in Tucson. Looking back into our species' past, he is investigating whether our ancestors' athleticism may even have accelerated the evolution of their intelligence millions of years ago. Our brains may, in fact, be a by-product of our brawn.

6. The link between fitness and the performance of simple cognitive tasks was first suggested by studies in the 1960s, but its importance became more greatly appreciated about 30 years later. In the 1990s, Fred Gage, a geneticist at the Salk Institute in La Jolla, California, found that exercise seemed to cultivate the growth of new neurons in mice. At about the same time, Arthur Kramer, a cognitive psychologist at the Beckman Institute for Advanced Science and Technology at the University of Illinois, published a paper in Nature showing that previously sedentary adults who undertook an aerobic fitness plan for six months boosted their performance in cognitive drills that required executive control. That's the kind of concentration that helps you to switch between different tasks without making mistakes, and it is a key contributor to more general intelligence.

7. Building on these experiments, a spate of later papers tracked people's fitness and cognitive skills over several years, sometimes decades. Initially, most of the investigations examined older people whose mental abilities were expected to lose their shine with age. One German study, published in 2010, tracked 4000 Bavarians over the age of 55 for two years. It found that those who rarely took part in physical activities were more than twice as likely to suffer from a cognitive impairment by the end of the study than those who engaged in exercise such as gardening, swimming or cycling a few times a week.

8. Another study, which had followed a group of nearly 1500 people for 20 years, showed that these effects may be long lasting. Those who exercised at least twice a week during middle age were much less likely to develop dementia by the time they reached their 60s and 70s, even when potentially confounding factors such as education, drinking and smoking were taken into account. The results should serve as a warning for couch potatoes: building good habits now could delay your mental decline in decades to come.

9. Although there are fewer studies of younger people, the available evidence suggests that physical activity enhances brain health at every stage of life. Some of the most striking statistics concern children aged 5 to 14 attending state-funded schools in New York City. Students in the top 5 per cent of the fitness rankings scored 36 percentile points higher on standardised academic tests than students ranked in the bottom 5 per cent. Similar results come from the records of 1.2 million men who enlisted for military service in Sweden between 1950 and 1976, which allowed researchers to compare the men's physical education grades at 15 with their cardiovascular performance at 18. Changes in fitness during these teen years seemed to correlate with the young men's intelligence scores and cognitive abilities by the end of that time period.

10. Taken together, all this research is reshaping our view of the relationship between body and brain. "When I was first thinking about this, I thought maybe there's a baseline healthy brain, and physical activity might improve it from there," says neuroscientist Megan Herting at the University of Southern California's Keck School of Medicine in Los Angeles, who has studied the impact of exercise on children's development. "But now I feel it's the opposite – the high-activity kids might represent the baseline of how the brain is supposed to be active." The implication is that exercise is not an enhancer of normal cognition; it's a necessary condition.

11. What's behind the link? A short-term mood boost might be bringing some of the benefits. "People really enjoy that euphoric aspect of a runner's high and the clarity of mind you get from a routine workout," says Brian Christie, a neuroscientist at the University of Victoria in British Columbia, Canada. Stress can inhibit your brain's responses when solving a problem, blocking it from making the necessary connections. "If you go out for a walk, your stress levels usually plummet. And that's when the answer comes to you," Christie says. That might partly explain why fitter children tend to do better at their schoolwork, for instance.

12. Exercise probably contributes to more permanent changes too. As one of the body's most energy-hungry organs, the brain relies on a steady supply of nutrients and oxygen through an intricate network of capillaries. Physical activity can encourage the construction of these supply lines, and it can also ease their maintenance. Matthew Pase at the Swinburne University of Technology in Melbourne, Australia, has found that high blood pressure, particularly in the central large arteries that feed the brain, can lead to a slump in cognitive performance, perhaps because it damages those vessels. Since regular physical activity reduces blood pressure, it should protect the brain's food supply from this undue stress.

13. Improved fitness also cuts the risk of diabetes and obesity. These problems disrupt the brain's insulin system, which is thought to trigger a cycle of reactions that contribute to the build-up of the plaques linked to brain damage in people with Alzheimer's disease.

14. Alongside these changes to the brain's overall health, exercise has been found to spur the release of neurotransmitters like serotonin, noradrenaline and dopamine, which help regulate signalling in the brain. These neurotransmitters are the same ones that antidepressants and drugs for attention-deficit hyperactivity disorder act on, which is why a bout on a treadmill or bicycle is akin to taking a mix of the drugs Prozac and Ritalin, says Ratey. It also prompts the brain to send out growth factors such as insulin-like growth factor-1 (IGF-1) and brain-derived neurotrophic factor (BDNF), which Ratey calls "Miracle-Gro for your brain" because it creates an environment where neurons can flourish and promotes the formation of new connections between cells.

15. The roots of this connection between body and mind probably lie deep in our evolution. "Physical activity is a strong part of our evolutionary history. Our whole physiological system is built on being athletic," Raichlen says. Perhaps the brain boost emerged to improve navigation. As animals forage and search for food, the surge in growth factors that accompanies their movements could encourage the neural and synaptic growth that helps them to remember the path, so they can revisit the spot later on.

16. Alternatively, the link could just be an evolutionary accident, Raichlen says. "It may be that you're upregulating these things to improve your ability to exercise and the effects in your brain are a by-product."

17. Even if that's the case, it may still lie behind some profound events in our prehistory. Raichlen points out that humans have far greater athletic endurance than our primate relatives – you wouldn't find a monkey running a marathon. As our ancestors evolved for long-distance trekking to catch their food, they would have experienced a constant flood of those growth factors and neurotrophins that nourish the development of neurons and synapses. It is possible that the result was a leap in intelligence, Raichlen says.

18. A handful of studies so far offers some support for the hypothesis. A couple of years ago, Raichlen and his colleague Adam Gordon of University at Albany, State University of New York, measured the brains of various groups of animal species – including rodents, dogs, cats and ungulates – and used their maximum metabolic rate as a proxy for athleticism. Within each group, the species with greater capacity for physical activity tended to have bigger brains in relation to their overall body mass, than the less active animals.

19. Raichlen also cites experiments that attempted to mimic evolution in the lab, by selectively breeding animals for certain traits. Mice bred for long-distance running, for instance, showed higher baseline levels of growth factors, along with a ramped up production of new cells in the hippocampus and marked brain growth in other regions, including the mid-brain. And looking at the anatomy of early humans, Raichlen recently studied the evolution of traits like longer limbs – an indication of the capacity for more strenuous physical activity. His results, published earlier this year, suggest that greater athleticism went hand in hand with increasing brain size – although he stresses that we are still missing direct evidence that the one caused the other. "The evolutionary story is really under-studied," he says.

20. Whatever role exercise played in our evolution, the brain-enhancing consequence of exercise has serious implications today. The US Department of Health is now encouraging schools to offer more physical education and the Institute Of Medicine recommends that elementary school children get 30 minutes of physical activity a day, and then 45 minutes daily in middle and high school. "We need to have kids moving every day, not just because it makes sense health-wise, but because it raises test scores," Ratey says.

21. The same principle applies to the older population, and offers an alternative to cognitive training strategies, such as brain teasers, that are often touted as ways to sharpen the ageing brain. There's currently not a lot of evidence to back these up, says Kramer, since the improvements gained in the specific cognitive training tasks don't seem to translate to everyday life. In contrast, new exercise regimes, typically conducted over six months or a year, tend to accelerate processing speed and improve attention and memory in all kinds of activities. Early results suggest that combining both approaches may be best of all.

22. What kind of exercise is ideal? An aerobic workout is essential, but depending on your current fitness it doesn't have to be too strenuous. Kramer has found that even gentle activities, such as taking a walk a few times a week, worked wonders for some elderly volunteers – increasing the connectivity of their brain networks and the size of their hippocampi, and boosting overall recall.

23. For those who are already in good shape, Ratey advocates a kind of exercise called high-intensity interval training (HIIT), which consists of very short, very hard bursts of exercise. Pushing your body in this way triggers the pituitary gland to release human growth hormone, he says, which in turn enhances neurotransmitter levels. As evidence for HIIT's effectiveness, Ratey cites a German study in which participants incorporated two 3-minute intervals of high-intensity sprinting into a 40-minute run. They produced much higher levels of BDNF and noradrenaline, and performed 20 per cent better in a post-run vocabulary-building exercise than those who had taken more leisurely exercise. However, Ratey cautions that HIIT is something that first-time exercisers should build towards slowly.

24. Ratey practises what he preaches, exercising at least three times a week for 20 minutes, with six 30-second high-intensity intervals in each session. The regime produces results without requiring a lot of time, he says. Kramer, who is now 60, also finds time to apply his discoveries to his life. He once climbed mountains, and ran marathons for many years, but these days he gets the bulk of his exercise on a stationary bike, where he can read the newspaper while he works up a sweat. At work, he uses a standing desk and walks between 30 minutes to an hour each day on a treadmill underneath it. It's never too late to begin getting these benefits, says Kramer. "I'm often asked, 'If I'm 70 will it help me?' The answer is: absolutely, yes."

25. But a new chapter is beginning in our understanding of the influence of physical exercise on cognition. Researchers are starting to find more specific effects related to different kinds of exercise. They are looking beyond the standard recommendation of 30 minutes of moderate, aerobic exercise a day, for the sake of your brain. Are there benefits to going slower or faster, or to lifting weights, or performing sun salutations? Whether you want a boost in focus for an exam, find it hard to relax or are keen to quit smoking, there's a prescription for you.

26. The first clue that exercise affects the brain came from rodent studies 15 years ago, which showed that allowing mice access to a running wheel led to a boost in neuron formation in their hippocampi, areas of the brain essential for memory. That's because exercise causes hippocampal neurons to pump out a protein called brain-derived neurotrophic factor (BDNF), which promotes the growth of new neurons/cells. The mice showed improvements in memory that allowed them to navigate mazes better.

27. The findings were soon translated to humans. Older adults who did aerobic exercise three times a week for a year also grew larger hippocampi and performed better in memory tests. Those with the highest levels of BDNF in their blood had the biggest increases in this brain region.

28. The idea that exercise helps to improve memory has been especially welcome given that the search for effective treatments for cognitive decline has been slow in progress. And it now seems that aerobic exercise such as running and cycling may help stave off Alzheimer's disease and other forms of dementia.

29. As the evidence for aerobic exercise accumulated, Teresa Liu-Ambrose at the University of British Columbia in Vancouver, Canada, began to wonder about other types of exercise. She has been looking for ways to halt dementia in people with mild cognitive impairment (MCI), a population of adults known to be at increased risk of developing dementia, and was especially interested in strength training, which has in recent years been added to US and UK government recommendations for physical activity.

30. To test the idea, Liu-Ambrose compared the effects of aerobic exercise and strength training in 86 women with MCI. She measured their impact on two abilities known to decline as the condition progresses: memory and executive function – which encompasses complex thought processes, including reasoning, planning, problem-solving and multitasking. Twice a week for an hour, one group lifted weights, while the other went for brisk walks quick enough that talking required effort. A control group just stretched for an hour instead. After six months of this, both walking and lifting weights had a positive effect on spatial memory – the ability to remember one's surroundings and sense of place.

31. On top of that, each exercise had unique benefits. The group that lifted weights saw significant improvements to executive function. They also performed better in tests of associative memory, which is used for things like linking someone's name to their face. The aerobic-exercise group saw improvements to verbal memory – the ability to remember that word you had on the tip of your tongue. Simply stretching had no effect on either memory or executive function.

32. If aerobic exercise and strength training have distinct benefits, is combining them the way to go? To address this, Willem Bossers of the University of Groningen in the Netherlands split 109 people with dementia into three groups. One group walked briskly four times a week for 30 minutes; a combination group walked twice a week and strength-trained twice a week for 30 minutes each; and a control group did no exercise. After nine weeks, Bossers put the participants through a battery of executive-function tests that measured problem-solving, inhibition and processing speed. He found that the combination group showed more improvement in executive function than the aerobic-only or control groups. "It seems that, for older adults, walking only is not enough. They need to do some strength training," he says. And these benefits extend to healthy adults too. In a year-long trial of healthy older women, Liu-Ambrose found that lifting weights, even just once a week, resulted in significant improvements in tests of executive function. Balancing and toning exercises, on the other hand, did not.

33. The combination of lifting weights and aerobic exercise might be particularly powerful because strength training triggers the release of a molecule called insulin-like growth factor-1 (IGF-1), a growth hormone produced in the liver that is known to affect communication between brain cells, and to promote the growth of new neurons and blood vessels. On the other hand, aerobic exercise mainly boosts BDNF, says Liu-Ambrose. In addition, Bossers says strength training also decreases levels of homocysteine, an inflammatory molecule that is increased in the brains of older adults with dementia. By combining aerobic exercise with strength training, you're getting a more potent neurobiological cocktail. "You're attacking the system in two ways," he says. The studies so far haven't addressed how long the effects last, but preliminary findings suggest adults will have to keep exercising to maintain the benefits.

34. Another approach is to start young, with findings that different types of exercise affect a child's mental capacity in a number of ways. For example, if you want kids to focus for an hour – on a maths test, say – the best bet is to let them have a quick run around first. That's according to studies that show a simple 20-minute walk has immediate effects on children's attention, executive function and achievement in mathematics and reading tests. Letting kids sprint or skip about has the same effect. A brisk walk can also help children with attention-deficit hyperactivity disorder to focus, although again it's not yet clear how long the effects last.

35. Daniel Schwartz practises what he preaches. During our interview he is strolling through Stanford University's leafy campus, an activity that according to his research boosts divergent creativity – otherwise known as thinking outside the box. It is walking at a leisurely, everyday pace that does this, not at a speed that would be aerobically challenging or make you out of breath. In Schwartz's study – which he thought of while out on a walk – people came up with more unique uses for everyday objects when walking outside or on a treadmill than when seated. He even found that taking a walk has a stronger effect on creativity than IQ. And people continued to be more creative afterwards, suggesting a saunter before a brainstorming session is a good idea.

36. Or, if you're more of a jitterbug, Peter Lovatt, a dance psychologist at the University of Hertfordshire, UK, suggests you "put on some music and start having a boogie", and the key is to keep it loose. After a session when people had to improvise dance moves, they came up with more creative answers to problems than after a structured dance session or no dancing at all. It seems that creative movements – no matter how silly – lead to creative problem-solving. In fact, the sillier the better: the trick is to move in different ways. So if you tend to move your arms a lot when you dance, focus on your hips instead. "Having a spontaneous wiggle – without any pre-planning – is really good for divergent thinking," Lovatt says.

37. These findings should be used to make decisions about the daily school routine, says Charles Hillman at the University of Illinois at Urbana-Champaign, who carried out some of the research. He agrees with current recommendations that children get at least an hour of exercise daily, but notes that it might be best spread over the course of the day. Because purely aerobic exercise keeps kids focused in the near term, giving them breaks to walk or move around every 2 hours might be the best way to promote learning.

38. In contrast, exercise that is highly structured and focused on specific skills, such as for a sport or to improve coordination, hampers attention. A bunch of drills and rules may be too taxing for children right before a test or a situation that requires sustained focus. Instead, these kinds of specific exercises seem to build up attention span gradually over the long-term. In research yet to be published, Maria Chiara Gallotta at the University of Rome in Italy found that twice-weekly sessions of coordinative exercises, such as basketball, volleyball or gymnastics practice, over the course of five months helped children do better on tests that required concentration and ignoring distractions. The cerebellum has been long known to be involved in coordinating movement, but is now recognised as having a role in attention as well. Practising complicated movements activates the cerebellum and, by working together with the frontal lobe, might improve attention in the process.

39. Making sure children are physically fit can have lasting cognitive benefits too, says Hillman. He has shown that children who are fit have larger hippocampi and basal ganglia, and that they perform better in attention tests. The basal ganglia are a group of structures important for movement and goal-directed behaviour – turning thoughts into actions. They interact with the prefrontal cortex to influence attention, inhibition and executive control, helping people to switch between two tasks, such as going from sorting cards by colour to sorting cards by suit.

40. Hillman focuses on children aged 8 to 11 because areas like the hippocampi and basal ganglia are still maturing, so intervening at a young age can make a big difference.

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