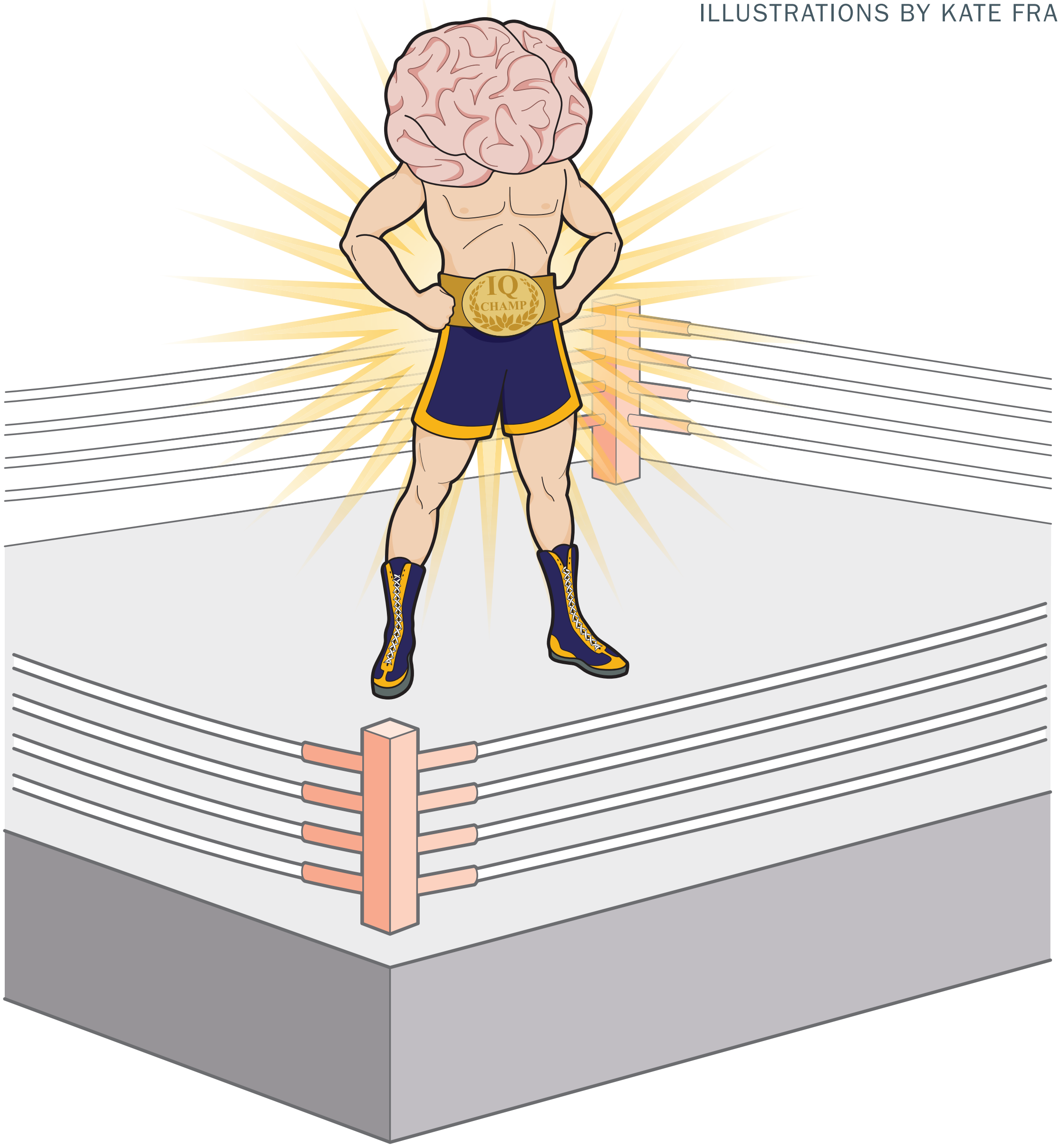
# BUILDING BETTER BRAINS

Recent studies indicate that some types of brain training can **make you smarter**

By John Jonides, Susanne M. Jaeggi, Martin Buschkuehl and Priti Shah

ILLUSTRATIONS BY KATE FRANCIS



If you want to strengthen your abdominal muscles, you can do sit-ups. Tone your upper body? Push-ups. To flex your intellectual muscles, however, or boost your children's academic performance, the answer is less clear. An exercise to stretch memory, tighten attention and increase intelligence could improve children's chances of coasting comfortably through life—and give adults a leg up as well.

The very notion flies in the face of conventional wisdom. Most people presume that no matter how hard they work, they are not going to get any smarter. Some subjects in our research laboratory, though, have increased their IQ scores after training their brain for as little as three weeks. The improvement can be significant enough that, anecdotally at least, a few participants noticed a difference in their daily activities. One individual, for example, reported sharper chess skills, stating, "I can plan further ahead." Another said that it felt easier to sight-read music while playing the piano.

How is this possible? Researchers have long believed that fluid intelligence—which reflects how well you tackle a new task rather than what facts you possess—is a fixed attribute, directly inherited or acquired very early in life. Indeed, evidence shows that fluid intelligence, as with height, is highly heritable, by some estimates as much as 50 to 80 percent. Yet intelligence can still be honed. Just as nutrition can influence height, environmental variables can also either brighten or beleaguer minds. Consider the Flynn effect: over at least the past 65 years measured intelligence, such as scores on the SAT, has steadily increased even though the genetic constitution of the population has not changed measurably.

Because high fluid intelligence typically leads to academic achievement and career success, scientists have long sought to alter it by various means, among them teaching reasoning strategies and test-taking skills. Most of these pursuits have met with limited or no success. More recently, though, in our laboratories and others, researchers have begun exploring the idea that some cognitive training activities—in particular, tasks that exercise working memory—can make a difference. Working memory, also referred to as short-term memory, keeps vital information at the ready so that other parts of the brain can tap it to solve problems. Mental arithmetic, for example, relies on working memory. More broadly, this storage system in the brain appears to be one of the key components of fluid intelligence.

Many studies find that variation in working memory accounts for at least 25 percent of the variation in fluid intelligence among individuals. Our own research confirms that inculcating this skill can lead to higher scores on standard tests of fluid intelligence for children and adults alike. Surprisingly, the training does not appear to expand the capacity of working memory but rather the ability to tune out distracting information. Furthermore, we and other researchers have found that as training progresses, the brain regions taxed by working memory become less active, as if they become more efficient in their functioning. These same areas are more engaged, however, when the brain is at rest. This pattern suggests to us that our program leaves the brain better primed to perform a wide array of tasks.

FAST FACTS

### How to Increase Intelligence

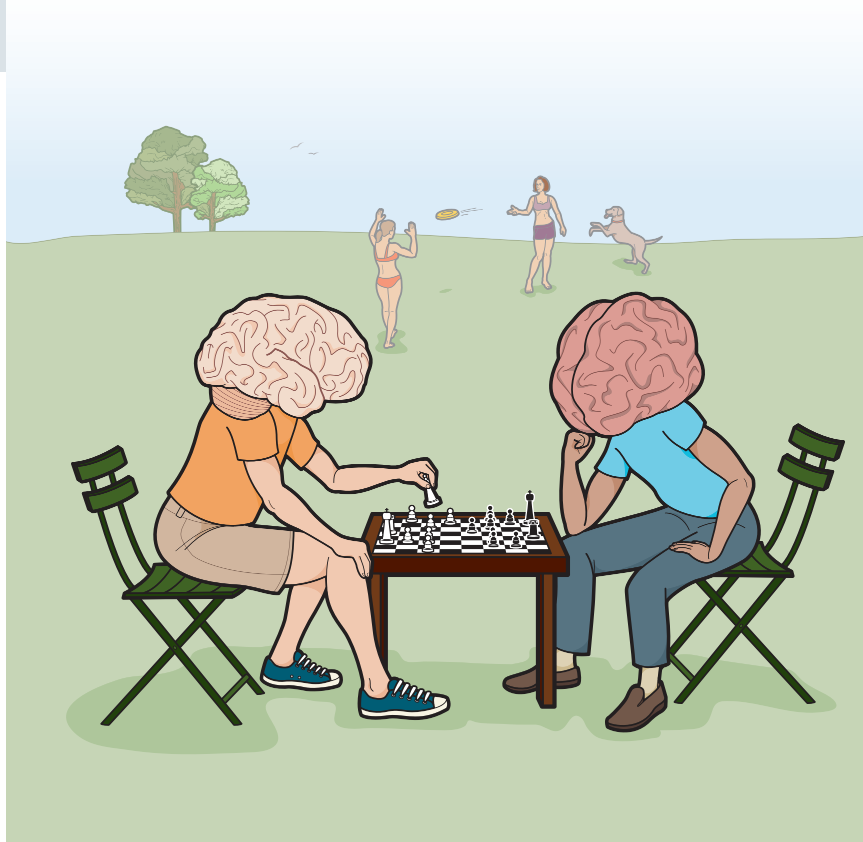
1» Scientists have long held that fluid intelligence—reflected not by what you know but rather how well you solve novel problems—is largely inherited and relatively impervious to improvement.

2» A raft of recent investigations, though, shows that some types of brain training—specifically those that exercise working memory and other so-called executive functions—can raise an individual's fluid intelligence.

3» Working memory training appears to boost fluid intelligence in children and adults alike. As training progresses, the brain regions taxed by working memory become less active when called on and more active at rest. This pattern suggests that certain training programs leave the brain better primed to perform a wide array of tasks.

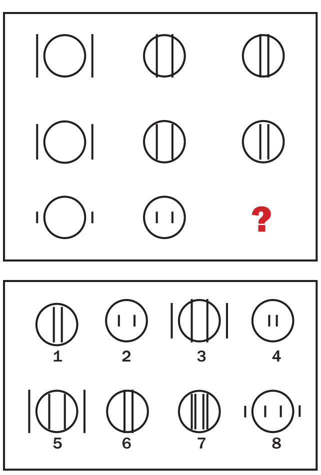
## Practice Makes Smarter?

During the 1990s psychologists and neuroscientists made great strides in understanding the basic cognitive processes that underlie fluid intelligence, in particular the importance of the prefrontal cortex, the brain region responsible for so-called ex-



ecutive function. Located just behind the forehead, the prefrontal cortex regulates attention, modulates impulses and coordinates information coming from other brain centers, among other complex tasks. These functions enable you to form plans, make decisions, spot errors and break habits. As scientists gained more insight into these faculties, the question naturally arose: Can any kind of intervention strengthen them and might that lead to greater reasoning abilities?

Torkel Klingberg and his colleagues at Sweden's Karolinska Institute published one of the first studies aimed at this question. In 2002 they developed a specialized computer program to exercise working memory and gave it to seven youths who suffered from attention-deficit hyperactivity disorder (ADHD). They asked another seven children with ADHD to play easier computer games. After five weeks the group who had practiced the working memory–based intervention saw a lessening of some of their symptoms—specifically, they squirmed less. Even more astonishing, they also raised their scores on a well-established measure of fluid intelligence. Klingberg's initial sample was extremely small, but he found the same effect in a later study of 44 children. His findings inspired other cognitive scientists to look more closely at executive function as a way to enhance IQ.




This spatial-reasoning problem resembles those on a well-known test of fluid intelligence often used by us and by others in various studies. Participants must decide which figure best completes the 3 x 3 matrix shown. Note how the two bars change size and position. Only answer 4 follows this pattern.

During the past decade many research groups have produced encouraging results. Training kids' attention has been shown to lead to higher intelligence scores; musical instruction appears to offer benefits, too. Children from a low socioeconomic background have experienced large jumps in IQ scores—on average 13 points—in as little as 20 hours after playing board and card games that exercised their reasoning skills. Older adults improved their fluid intelligence after playing the video game Rise of Nations, as well as after practicing exercises that tax working memory.

To design our own intervention, we wanted a task that would make you juggle several pieces of information in your head, shifting your attention from one to another. We targeted these specific skills by modifying a well-known working memory task, the *n*-back test—so called because participants are asked to keep track of an image, number or letter that appeared *n* positions back in a series.

In a 2-back version of our training task, subjects viewed a series of squares at different locations on an otherwise blank computer screen [*see box on page 63*]. For every square, participants had to decide whether it was positioned in the same spot on the screen as the shape shown before last. A more difficult exercise, a dual *n*-back task, requires participants to match both a visual and auditory cue—locations on the screen, say, and a letter they hear spoken through headphones. One critical feature of our training program is that we can adjust the difficulty by raising the value of *n* in the *n*-back test, just as you might increase the speed of a treadmill to keep yourself challenged while exercising. In this way, we gave our participants' working memory an actual workout, tailoring the training program as their ability changed over time.

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WE BELIEVE THAT OUR **N-BACK TRAINING** IS LIKE A CARDIOVASCULAR ROUTINE, TARGETING MANY ASPECTS OF OUR **REASONING ABILITIES**.

## No Pain, No Gain

By varying the difficulty of these tasks, we hoped to exclude the possibility that our subjects might improve simply by virtue of repetition or by developing specific strategies or habits. We wanted them thinking on their feet. Scientists have long debated whether brain training can actually make you smarter or whether it simply makes you better at the particular task you practiced. Consider people who compete in memory competitions, for example. They train to memorize some 200 names of strangers or the exact order of all the cards in a shuffled deck. Although they perform astonishing feats of recall, these tricks do not actually make them more intelligent. Memory training may be a lot like learning to shoot an arrow—although your archery skill improves, your overall fitness stays about the same. Our calibrated *n*-back training, we believe, is more like a cardiovascular routine, targeting many aspects of our reasoning abilities.

In one experiment in 2008 we tested the fluid intelligence of 70 young adults. We then divided them into four groups who trained on the dual *n*-back task for one, two, three or four weeks each. An additional group received no training at all. We then retested all the subjects. The scores of the untrained individuals remained more or less constant. All four groups, however, attained higher scores on the later intelligence test. More training led to greater achievement, so the people who practiced for a month made the most dramatic gains. Another study of 65 older adults produced similar outcomes.

Children displayed greater variability. To test them, we devised a version of the *n*-back task that resembled a video game [*see box on opposite page*]. Participating youth—who were on average nine years old—trained for four weeks. A second group of similarly aged children spent the month using a "knowledge trainer"—software that coached them on general facts and vocabulary items to develop what is known as crystallized intelligence.

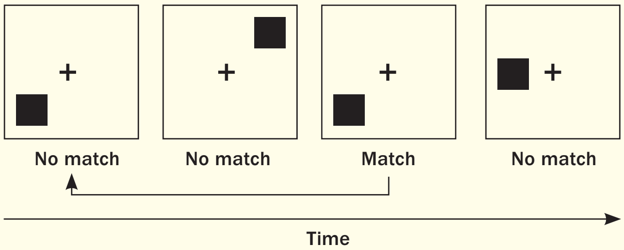
Not all the children who trained on the *n*-back task succeeded in building working memory skills. Some showed little interest in it, whereas others seemed to grow overly frustrated as the difficulty increased. Children who showed the most improvement, however, also earned higher scores on intelligence tests after the program. Even three months later, with no further training, these children preserved a good deal of their increases in fluid intelligence. The young people who used the knowledge trainer saw no such benefits.

## Mental Conditioning

When we looked more closely at what might be changing as a result of this intervention, we found that the *n*-back training renders people psychologically more conservative over time. In other words, those who practiced the task learned to resist the impulse to respond automatically to a stimulus. One recent study demonstrates this effect: children who become more cautious over time on *n*-back tests also show greater reservation in a related exercise, in which they are told to say "yes" to any letter except X. About 90 percent of the letters presented were not Xs, and the children quickly got into the habit of saying "yes," producing quite a few errors as a result. After a course of *n*-back training, though, the children became slower to respond, and the number of incorrect "yeses" dropped considerably.

We also wanted to know what underlying brain differences might explain the changes we were observing. Using functional MRI, we scanned 26 participants as they performed *n*-back tasks and during a rest period when they simply lay awake with their eyes open. Every day for a week the subjects used our *n*-back training exercise, and then we scanned them again. Initially we found the greatest activation in parts of the prefrontal and parietal cortex, just behind the frontal cortex—a pattern that is quite stan-

## A Working Memory Workout




In a visual 2-back working memory task for adults, participants watch a series of squares that appear in different locations on a computer screen. They must press a key whenever the square lands in the same position it was in two spots back in the series. Thus, in the sequence shown above, test subjects would respond to the third square. Children can train their working memories using programs that present *n*-back tasks in the form of video games. In the example at the right, a frog jumps from one lily pad to another; the children must press a key when the frog lands on the same pad as the one he was on *n* jumps before. To make the program more appealing for youngsters, we present it within a story about a magic frog prince.

dard for tasks that involve working memory. After training, however, we saw less activation in these regions. Despite improved performance, the *n*-back test elicited less neural activity after a week of practice. Working memory training, it seems, leads to more efficient brain activation, somewhat like a car engine that no longer needs to work as hard once it has kicked into a higher gear. This drop in activity as proficiency grows has solid support—psychologist Richard Haier of the University of California, Irvine, for example, has shown that people use less brainpower to play Tetris as they become increasingly adept at the game.

Yet our study produced another intriguing result. When we looked at the scans of our subjects' resting brains, we saw higher levels of blood flow after training than before in selected regions that largely overlapped the ones mentioned above. We surmise that the parts of the brain that become more efficient through training are left better prepared for the task while at rest; that is, they are more fit. This conditioning may help explain how *n*-back training leads to improvements on different working memory tasks and general intelligence tests. It might also account for how the effects induced by these activities can outlast the training period itself.

Of course, the training and transfer effects we have documented vary from person to person, for reasons that are yet to be fully explored. For example, we have found that an individual's beliefs about the malleability of intelligence can affect how much they improve. Subjects who have some intrinsic motivation to train also find the endeavor more effective.

We are at the opening bell in investigations of cognitive training and its benefits. We have yet to learn how long the effects last and how to make the activities suitable for educational settings. More important, we do not yet know to what extent the improvements we see affect academic achievement and other real-life consequences. Still, we have every reason to believe that making people smarter might help them to lead happier, healthier lives. M



## (Further Reading)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- **Short- and Long-Term Benefits of Cognitive Training.** Susanne M. Jaeggi, Martin Buschkuehl, John Jonides and Priti Shah in *Proceedings of the National Academy of Sciences USA,* Vol. 108, No. 25, pages 10,081–10,086; June 21, 2011.
- **Short-Term Music Training Enhances Verbal Intelligence and Executive Function.** Sylvain Moreno, Ellen Bialystok, Raluca Barac, E. Glenn Schellenberg, Nicholas J. Cepeda and Tom Chau in *Psychological Science,* Vol. 22, No. 11, pages 1425–1433; November 2011.