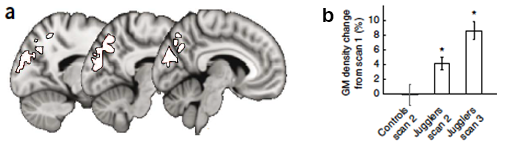
**Your brain is plastic.**

Really. Your brain is plastic. Well, not plastic like Tupperware, but plastic in the sense that it is moldable, changeable, and flexible. When you take on difficult mental tasks, your brain gets busy rewiring itself in a process that is very analogous to the way your muscles build themselves up each time you work them hard.

Scholz et al. (2009) studied the brains of people learning to juggle (Figure 1 below). They found that the density of grey matter increased and the structure of white matter changed in those that learned to juggle, even after just a few weeks. People's brains were changing in response to new demands.



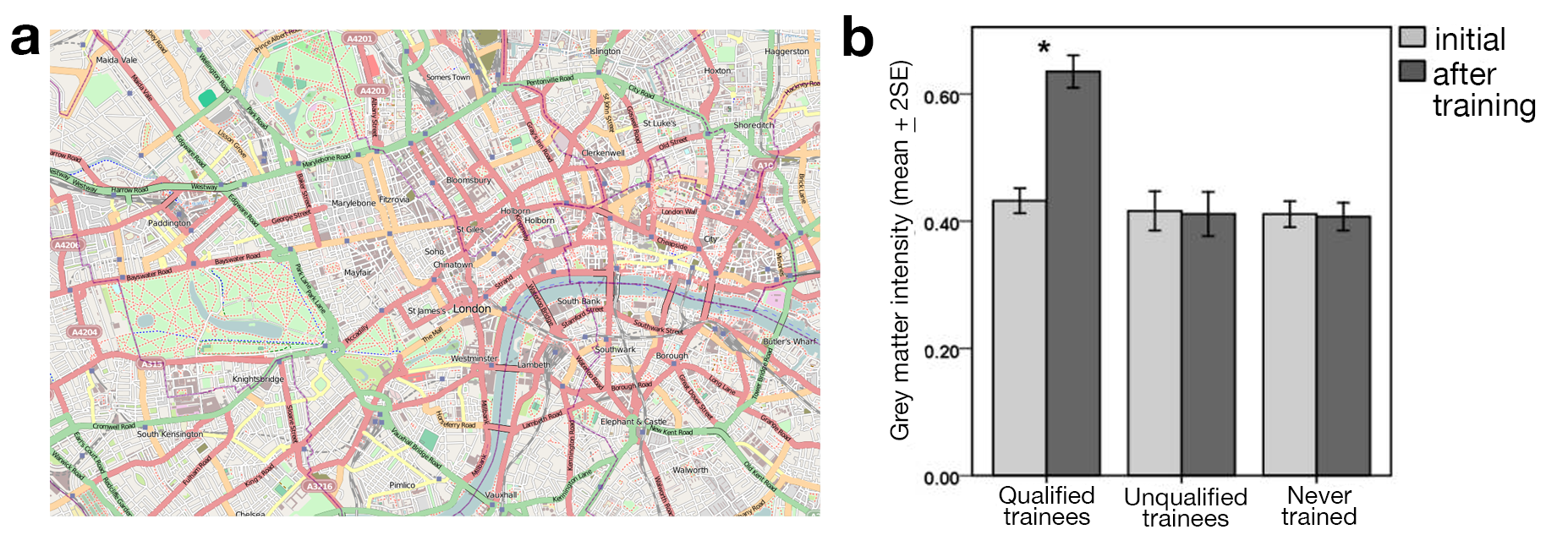
*Figure 1. A) Outlined white areas show areas of increased grey matter density from scan 1 (pre-training) to scan 2 (after six weeks of training). B) People that did not train (the control group) saw no increase in grey matter density during the experiment, while those training to juggle saw increases at scan 2, and again four weeks later with no additional training (scan 3).*

Our previous analogy between brain growth and muscle growth is apt. If you do 20 push-ups a day, pretty soon push-ups are easy for you. But at first, it may feel like a struggle, and it may hurt (physically and emotionally!). Despite the initial difficulty, we wouldn't conclude that someone just isn't able to do push-ups, or that they were born without some essential skill.

Yet, with mathematics, some people experience that "pain" of doing new, difficult work and conclude that they don't have a gift for math. Unfortunately, their parents and teachers may reinforce this message, despite good intentions. But just as no one is born to do push-ups, no one is born to do math. Everyone has to work at it, and there is no easy answer except to do the hard work, push through the initial pain, and know that the work will pay off. "Growing" your brain *should* feel a lot like growing your muscles... hard but satisfying. It also gets easier and easier the more you do!

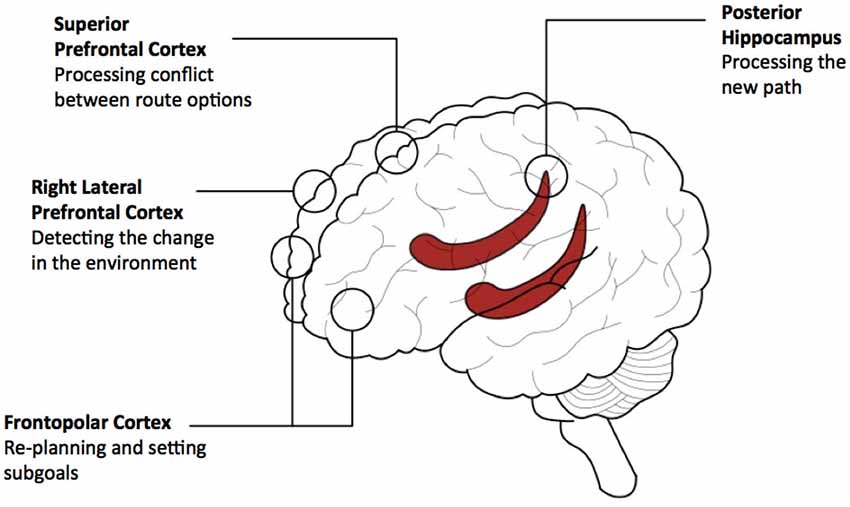
Need more dramatic evidence that your brain can grow? In London, prospective cab drivers have to pass a tremendously demanding test of the crowded, complex, and anachronistic road network of that old city. To pass the test is a tremendous feat of

spatial memory. Woolett and Maguire (2011) examined the brains of people studying for the test (Figure 2). People who studied for (and passed!) the test had developed more grey matter in their posterior hippocampi (brain areas known to be associated with spatial reasoning). People who worked hard grew their brains, quite literally.

**

*Figure 2. A) No, this is not a brain map... but rather a street map of London. What a mess! B) Results before and after subjects studied for their test of London streets. Those that stuck with it, studied hard, and qualified to be cabbies (qualified trainees) had an increase in gray matter density in their hippocampi, but those that gave up on the training (non-qualified trainees) or never trained (controls) did not see an increase in gray matter. Panel A from openstreetmap.org; panel B modified from Woollett and Maguire 2011.*

When researchers asked subjects to consider detours to preferred driving routes, a symphony of activity across many parts of the brain was triggered (Spiers and Gilbert 2015; Figure 3 below). Challenging mental tasks require connections between parts of the brain.



*Figure 3. From moment to moment as someone considers a detour, different parts of their brain activate to handle the different cognitive processes. From Spiers and Gilbert 2015.*

**What does cutting edge brain research mean about you, and your ability to learn mathematics? There are three key lessons:**

1. Expect learning to feel hard, especially at first. Expect it to feel as tiring (and as easy to procrastinate on) as running a mile.
2. Your brain will actively rewire itself to accommodate the demands you are placing on it. You won't have brain scans to look at, but trust that the feeling in your head is not just your imagination. There are physical changes happening in there!
3. What you put in is what you get out. You wouldn't expect to become a great basketball player, concert pianist, or artist without a lot of practice. Mathematics is no different. The way to get better at math is to do more math. No shortcuts.

The idea that you can increase your own brainpower through work is sometimes called a "***growth mindset***". Someone with a growth mindset believes they can increase their ability through effort. In contrast, someone with "***fixed mindset***" believes they are inherently good or bad at certain tasks, and there is little to be done about it. Growth and fixed mindsets aren't simply "good" and "bad" attitudes, respectively, but reflect a person's underlying view about how much they can improve. A growth mindset is very empowering, because it reinforces a person's control over their situation. A fixed mindset can be debilitating - if you really believe that no matter how hard you work, you won't get any better, you will almost certainly give up.

**Student Activity**

1. Identify these statements as exemplifying a "growth mindset" or a "fixed mindset". Just put "GM" or "FM" next to each statement.

Teacher says to student: "You sure are smart!"

Teacher says to student: "Wow... you worked really hard on this assignment!"

Coach says to player: "If we practice with discipline, we will play with discipline."

Coach says to player: "You are not cut out for this sport."

Player says to coach: "I just can't hit curveballs."

Student says to classmate: "Damn, I am not good at Physics."

Student says to classmate: "Wow... you got a 93% on the Physics test? You are so lucky that Physics just makes sense to you."

Young man says to friend: "My last three girlfriends have said I don't communicate, and eventually broke up with me. I am doomed to be alone forever."

1. Consider a few of your most favorite and least favorite activities and school subjects. Jot those down here:

For each, think back to some experience you've had and write down something you might have said, or that was said to you, and identify if that was a fixed or growth mindset statement.

**Journal Assignment**

For the next week, pay attention to your own thoughts and words, and those of your classmates/friends/roommates and your instructors. Record any statements that exemplify a growth or fixed mindset in your journal, and provide a little explanation or interpretation for each. Strive for at least three different examples. If you don't hear three such comments this week, try to remember something you've heard in the past, and indicate this was something from your past.

e.g., "My dentist mentioned that he didn't have the knack for orthodontic surgery. To me this sounded like fixed mindset, like he believed you either are good at surgery or not, instead of a growth mindset where you could improve in surgical skill through practice. This might be the rare example where a fixed mindset is ok, because I wouldn't want a surgeon practicing on me!"

**References**

Scholz J, Klein MC, Behrens T, Johansen-Berg H. 2009. Training induces changes in white-matter architecture. Nature Neuroscience 12:1370-1371.

Spiers HJ, Gilbert SJ. 2015. Solving the detour problem in navigation: a model of prefrontal and hippocampal interactions. Frontiers in Human Neuroscience 9:125. doi: 10.3389/fnhum.2015.00125

Woollett K, Maguire EA. 2011. Acquiring "the knowledge" of London's layout drives structural brain changes. Current Biology 21:2109-2114.