The Physics of fMRI

April 13, 2009 | Attention Deficit Disorders [1], Addiction [2]
By John J. Medina, PhD [3]

I almost destroyed the backseat pocket of an airline seat this summer. The vandalism was inadvertent, assuredly, though the anger that fueled it was not. While waiting for my plane to take off, I had read a magazine article claiming to show that fMRI (functional magnetic resonance imaging) studies were "uncovering" the voting preferences of test subjects. An adjacent article announced that researchers could now predict the buying preferences of other test subjects using the same imaging technologies.
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I was puzzled. How could Fourier transforms performed on signals coming from someone's cortex say anything about their politics? What could possibly have reduced the interpretation of these noninvasive imaging data to conceptual phrenology? I got so mad as I thought more about it that I jammed the articles back into the pocket, aggravating an already ripped inner seam.

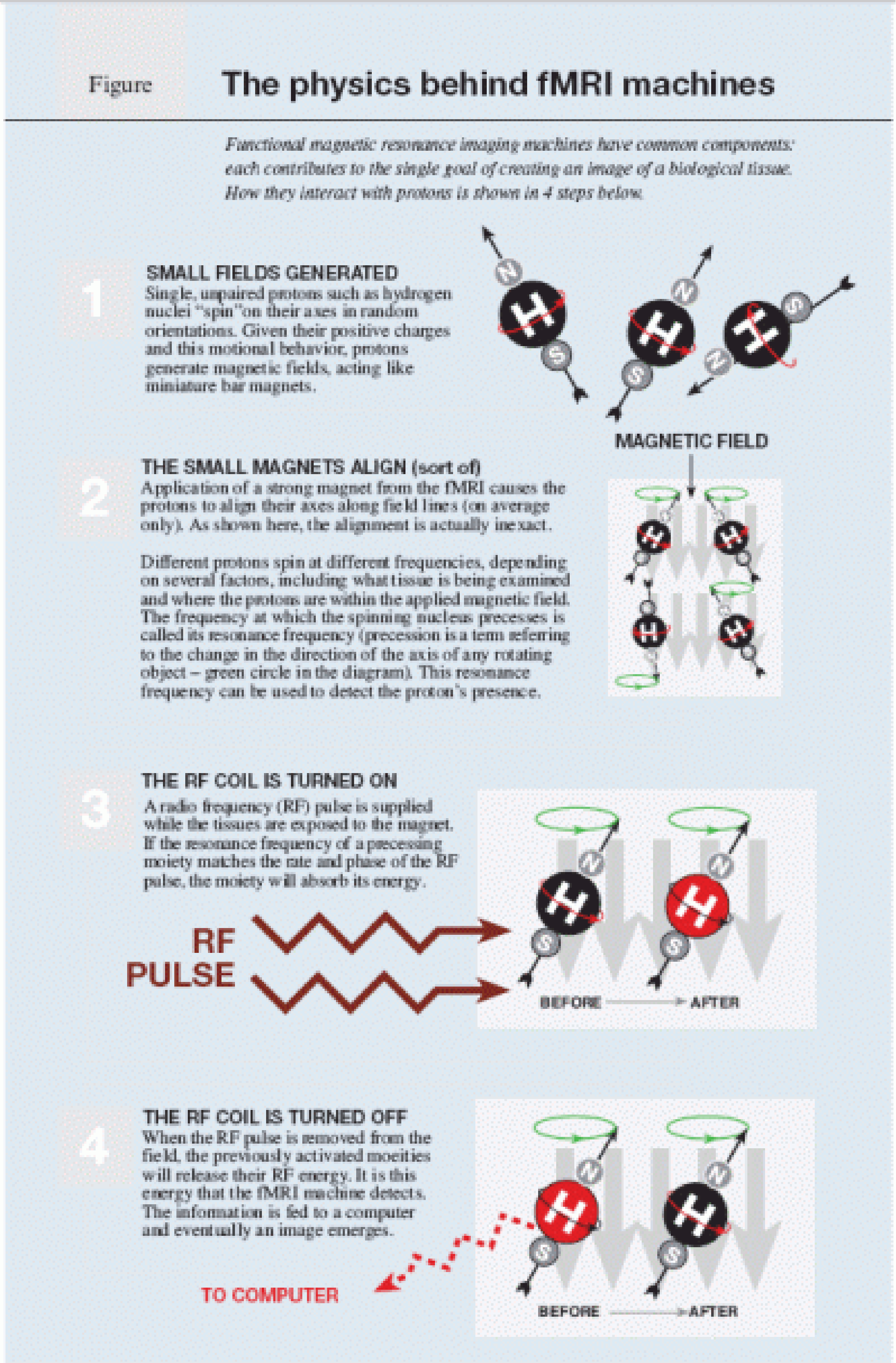
The column you are reading is an attempt to push this admittedly hot reaction into a more positive direction . . . and for a good reason. There are growing numbers of articles in the popular press describing "breakthroughs" in our understanding of human cognition—and how noninvasive imaging data are changing the way we view the brain. Nothing wrong with that, certainly. There has been an explosion of studies using functional (f)MRI technologies and their like. But are the data being revealed strong enough to predict subjective behaviors, such as voting habits? As you can probably guess from my tone, the answer of this bioengineer is "no," or at least "not yet."

I have decided to do something positive about these "headlines." For now, and in my next 2 columns, I will describe how fMRIs actually work and what is the least luxurious, most conservative way to interpret the view they give us about cognition. Given the conceptual and technical complexity, it is easy to misconstrue what imaging technologies can divulge about human cognition. Starting with quarks (literally) and ending with scans of emotional behavior, we will explore some of the biophysical underpinnings of this promising (and may I say limited) technology. The hope is that by knowing a bit about the technical aspects of fMRI, we will better understand what it can—and cannot—measure. This will allow us to treat with greater skepticism, and more sobered excitement, the view that fMRIs are giving us about how our brains work. This first installment deals with some basic physics. I review a few properties about magnets and radio waves that you might not have thought about since your undergraduate days. In part 2, I will focus on the types of molecular interactions these magnets and radio waves actually measure when trained on an actively thinking brain. The third column will relate how this knowledge reveals both the strengths and limitations of using imaging technologies to discover aspects of human cognition.

THE 40,000-FOOT VIEW

We begin with the name. As you know, fMRI is short for functional magnetic resonance imaging. The core idea of fMRI has been around for a long time. Originally called just NMR (nuclear magnetic resonance), this technology found great utility in the organic and inorganic laboratories. When it came time to apply the technology to biological tissues (from ideas originally developed by Paul Lauterbur), the word "nuclear" was thought to have too many negative connotations. It was dropped in favor of the more socially compatible "functional."

To understand how an fMRI scanner generates images, we have to break the machine down into its component parts. All fMRIs possess 3 general "gadgets." The first is a device that can generate a powerful magnetic field. The second is a coil that can create powerful radio frequency pulses. The third is a high-speed computer, preloaded with a lot of very sophisticated signal processing software, all programmed to produce an image capable of making sense to a researcher.



How these 3 gadgets work together is fairly easy to understand, at least at the 40,000-foot level (**Figure**). The magnet in the fMRI transforms tissues into a visualizable state; the radio frequency pulses provide the signaling information necessary to discern them. The computer assembles the information from the radio frequency pulses into a form instantly recognizable to anyone who can read a weather map. Indeed, part of the problem with misinterpreting fMRIs is that the information seems so accessible.

To make sense of how these gadgets work together, we have to understand how magnets and radio frequencies act at the subatomic level. These interactions are essentially the same physical processes you see on display every time you turn on your radio.

Why fMRIs need magnets

The most obvious characteristic of any fMRI machine is the magnet it carries. Modern magnets are constructed from superconducting wires cooled by helium. A typical fMRI can generate a magnetic field tens of thousands of times greater than the earth's. The force generated is so strong that patients have to remove any metal items before entering the shielded privacy of the scanner. (That's a safety issue. Flying metal objects, pulled off of uninspected individuals by the magnets, have injured and even killed people!)

Why do you need such beastly magnets? The reason has to do with the protons embedded in the biological tissues being examined and the odd motions these nuclear particles intrinsically possess. Three sets of facts describe why magnets are used.

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