What Neuroscience Can Teach Us about Human Nature and the Potential for Change

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The human brain is staggeringly complex. At birth, the brain typically contains more than 100 billion neurons, whose numbers slowly diminish with age. A piece of your brain the size of a grain of sand would contain 100,000 neurons, 2 million axons, and 1 billion synapses, all "talking" to each other. Given this complexity, how do we begin to understand the functions of the brain?

We believe that the real secret to understanding the brain lies not only in unraveling and mapping the structure and function of its modules but also in discovering how they interact with each other to generate the whole spectrum of abilities that we call human nature. For example, given that some portion of the brain's intricate circuitry is hardwired from birth, does it follow that those circuits cannot be altered? How much of the adult brain is modifiable? In this chapter, we describe two phenomenon, phantom limbs and synesthesia. These phenomena suggest that the detailed circuitry of the brain is im-

portant in understanding not only how we experience the world but also may have implications for creativity and even the evolution of language.

Learning from Curiosities

People who hear voices, feel missing limbs, see things that no one else does, and deny the obvious are not "crazy." Ninety-nine percent of the time they are telling the truth, and if it seems incomprehensible, that is usually because we are not smart enough to figure out what is going on in their brains. For the most part, they are lucid, rational, and no more insane than you or I, but each of them suffers from damage to specific parts of the brain that leads to bizarre but highly characteristic changes in behavior.

Enigmatic disorders have intrigued and perplexed physicians throughout history, but usually they are chalked up as curiosities and forgotten. We believe, however, that such patients are our guides into the inner workings of the human brain—yours and mine. Far from being curiosities, these syndromes illustrate fundamental principles of how the normal human mind and brain work, shedding light on the nature of body image, laughter, dreams, depression, and other hallmarks of human nature. By moving patients out of the clinic and into the laboratory, we can conduct experiments that help reveal the deep architecture of our brains.

The sense of mystery that lies at the heart of scientific pur-

suits is especially characteristic of the forays we make into understanding our own minds. For us, the best research strategy might be characterized as "tinkering." Indeed, we believe that being medical scientists is not all that different from being sleuths.

A key mystery that emerges when thinking about the brain is the extent to which all its intricate circuitry is innately specified by genes or to what extent it is acquired gradually as the result of early experiences, as when an infant interacts with the world. This is the well-known nature-versus-nurture debate, which has been going on for hundreds of years, yet we have barely scratched the surface in formulating an answer.

Phantom Limbs

The study of phantom limbs, interestingly, can shed light on this ancient nature-versus-nurture question. Phantom limbs are arms or legs, for example, that linger indefinitely in the minds of patients long after they have been lost in an accident or removed by a surgeon. Some patients experience excruciating pain in the phantom arm, hand, or fingers—pain that is not only unrelenting, but also untreatable; no one has the foggiest idea of how it arises or how to deal with it.

Phantom limbs were probably known since antiquity; not surprisingly, there is an elaborate folklore surrounding them. After Lord Nelson lost his right arm during an unsuccessful attack on Santa Cruz de Tenerife, he experienced compelling

phantom limb pains, including the sensation of fingers digging into his phantom palm. The emergence of these ghostly sensations led the sea lord to proclaim that his phantom was a "direct proof of the existence of the soul." If an arm can survive physical annihilation, why not the entire person?

This phenomenon is not rare: 99 percent of patients experience a phantom pain after an amputation. Why doesn't the mind accept the loss and "reshape" the body's image? Is the body image—and other aspects of the mind—so firmly laid down by genes that even the experience of an amputation cannot modify it?

The vividness of the phantom is enhanced by the presence of referred sensations: touch on other parts of the body is experienced as arising from the phantom. For example, after arm amputation, touching the face will often evoke precisely localized sensations in the phantom fingers, hand, and arm. Consider a patient who had lost his left arm above the elbow and was experiencing itching and painful sensations in his phantom fingers. He was blindfolded and, using an ordinary cotton swab, various parts of his body surface were stroked, with the patient telling us where he felt the sensations. He felt his chest, shoulder, back, leg, and so on being touched, but when the swab was moved around his cheek, he felt not only his cheek, but also his phantom thumb and fingers. Soon we had a complete map of the patient's phantom hand—on his face.

Of further interest is the fact that this referral of sensations is modality specific. For example, ice on the face elicits cold in the phantom fingers and vibration is felt as vibration. Even wa-

ter trickling down the face is felt, sometimes, as water trickling along the phantom arm.

What could explain this medical mystery of sorts? First, we need to look closely at the anatomy of the brain, particularly at how various body parts such as limbs are mapped onto the cerebral cortex, the great convoluted mantle of the surface of the brain. One part of the brain, the somatosensory cortex, is dedicated to processing information from the skin throughout the body. Each brain cell in this region has its territory on the body surface—its own small patch of skin, so to speak, to which it responds. We call this the cell's receptive field. A map of the entire body surface exists in the brain, with each half of the body mapped onto the opposite side of the brain. The brain's map is continuous except for one peculiarity: The face area of the brain, instead of being near the neck where you would expect it, is dislocated and lies beside the hand area.

Our reasoning is that after this patient's arm was amputated, no sensory signals were going to the hand area of the brain, leaving it hungry for new sensory input. Sensory signals normally come from the face skin only to the face area of the brain. However, when the adjacent hand cortex is silenced because the hand and arm are amputated, then the input from the face starts "invading" the vacated territory corresponding to the missing hand and starts activating the original hand area as well—a striking demonstration of plasticity in the adult human brain. Intriguingly, even though the hand area is now being activated by face skin, whatever is reading those signals higher up in the brain misinterprets them as coming from the

missing hand: when you touch the patient's face, he says you are touching his hand.

Follow-up brain imaging experiments on amputees corroborate this theory. For example, functional brain imaging techniques have shown changes in brain maps where, in this example, the left hand's area in the brain's right hemisphere is gone, invaded by the sensory input from the face. Such large-scale changes in the organization of the brain in adult humans flatly contradict one of the most widely accepted dogmas in neurology—the fixed nature of connections in the adult human brain.

In some patients, the phantom will develop a painful clenching spasm, and the patient cannot voluntarily "unclench" his fist even with intense effort. If a mirror is propped up vertically on the table parallel to the nose and if the patient views the reflection of his normal hand in the mirror, the reflection of the hand is seen superimposed on the felt position of the phantom, giving the visual illusion that the phantom has been resurrected. If he now moves the normal hand, the phantom is suddenly "animated" and is felt to move vividly. Sometimes this can lead to the unclenching of a previously clenched, painful phantom, suggesting a promising new therapeutic approach for phantom pain. The clinical usefulness of the procedure requires detailed evaluation, but the illusion suggests that a great deal of interaction can occur between vision and touch. Additionally, these results suggest that the traditional distinction between sensory and motor systems may have to be revised.

Although we ordinarily regard phantoms as pathological, it is relatively easy to generate such illusions, even in otherwise normal individuals. Consider the following illusion, the "phantom nose." Sit in a chair blindfolded, with a friend sitting at your side, or in front of you, facing the same direction. Have a third person stand near you, and with his left hand take hold of your left index finger and use it to repeatedly and randomly tap and stroke the nose of the second person, while at the same time he taps and strokes your nose in precisely the same manner using his right hand, in perfect synchrony. After a few seconds of this procedure, you will develop the uncanny illusion that your nose has either been dislocated or has been stretched out several feet forwards or off to the side, demonstrating the striking plasticity or malleability of our body image. The more random and unpredictable the tapping sequence, the more striking the illusion.

The implications are profound. First and foremost, our findings suggest that brain maps can change, sometimes with astonishing rapidity, as effects have been seen in patients just 24 hours after amputation. Thus, it is possible that the completely static brain maps in textbooks are highly misleading. It may be that, far from signaling a specific location on the skin, each neuron in the map is in a state of dynamic equilibrium with other adjacent neurons; its significance depends strongly on what other neurons in the vicinity are (or are not) doing. Second, these experiments suggest that the so-called body image, despite its appearance of durability and permanence, is entirely a product of the brain that can be profoundly altered by

one's life experiences. The body image is merely a shell, created temporarily for the sole purpose of successfully passing on one's genes to the next generation.

Synesthesia

Another striking example of cross-wiring in the brain is a phenomenon called synesthesia, or mingling of the senses. Synesthetes are otherwise perfectly normal people whose senses are mixed up. For example, every time they hear a specific tone, they experience a color, such that C-sharp might be red and F-sharp might be blue. Some of these people see colors when they see numbers. Every time they see a number five printed on a page, for example, it is tinged with color. For a given synesthete, five might be red, six blue, seven green, and so on. Different synesthetes experience different colors for letters and numbers, but for a given synesthete, the colors are the same throughout life. Similar to phantom limbs, this phenomenon is not rare: 1 in 200 people has it.

The first careful study of the phenomenon was conducted by Francis Galton, a cousin of Charles Darwin. His paper, published in *Nature* in 1876, focused mainly on the two most common types of synesthesia: the kind in which sounds evoked colors, and the kind in which different numbers always seem tinged with different colors. He pointed out that even though a specific number always produced the same color for any given

synesthete, the particular colors evoked were different for different synesthetes.

What can one make of these people? Is the world richer and more colorful for them in ways we cannot even imagine? Is synesthesia a blessing or a curse? Even though synesthesia has been recognized for more than a century, it has generally been brushed aside as a curiosity because it did not "make sense." Even now, it is often dismissed as bogus, with remarks such as, "These people are just crazy" or "They are acid junkies" (and, sure enough, LSD does have a reputation for inducing synesthesia).

Another common explanation of synesthesia is that these subjects are just experiencing childhood memories and associations. Maybe Charles had been playing with refrigerator magnets as a child and the number 5 was red and 6 was green. Of course, this theory does not explain why only some people remain "stuck" with such vivid sensory memories; while you might *think* of cold when you look at a picture of an ice cube, you probably do not *feel* cold, no matter how many childhood experiences you may have had with ice and snow.

A third common explanation is that these people are using vague tangential speech or being "metaphorical"—using unusual descriptions when they speak of C-major being red or chicken tasting "pointy," just as you and I speak of a "loud shirt" or "sharp cheddar cheese." Our ordinary language is replete with such synesthetic metaphors, and perhaps synesthetes are just especially gifted in this regard.

However, saying that synesthesia is "just metaphor" is not really saying much, because we do not have the foggiest idea of how metaphors work or how they are represented in the brain. Indeed, we turn the problem on its head and argue the opposite: namely, that metaphor *is* a form of synesthesia. Or, to put it differently, synesthesia is a concrete sensory process whose neural basis we can uncover, and that discovery in turn might provide clues for solving the more deeply enigmatic question of how metaphors are represented in the brain and how they might have evolved.

Our first question is, "Is synesthesia a genuine *sensory* experience for these subjects? For example, do they literally *see* the color red when looking at 5? And green with 7? Or do the numbers merely evoke childhood memories?" A simple clinical test proves synesthesia is real. Figure 1a at first appears to be a bunch of computerized fives with some twos scattered among them. Since the 2s and 5s are made up of identical features (three horizontal bars and two vertical ones), you cannot spot the twos except by a detailed, item-by-item inspection. Eventually, you can find all the twos and see that they form a shape, in this instance a triangle. If you show this figure to a synesthete, he or she will immediately see the triangle because the twos appear to be a different color and conspicuously pop out from the background, as in Figure 1b.

This strongly suggests that the synesthetically induced colors are genuinely sensory, not some high-level memory association or metaphor. Metaphors and memories don't pop out.

What might be the cause of synesthesia? We are struck by

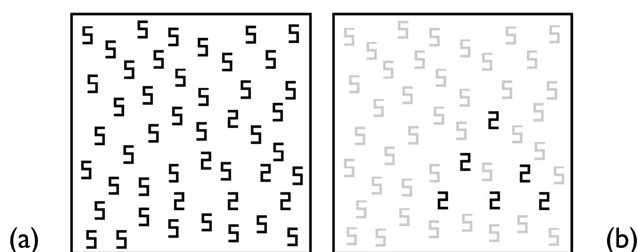

Figure 1. A synesthete will see the twos and fives in (a) clearly because they are different "colors," as shown in (b) with different shades of gray.

the fact that the number area and color area are right next to each other, almost touching, in the brain. We realize this probably isn't a coincidence—the most common type of synesthesia is the number-color type. We suggest, therefore, that the phenomenon is caused by a cross-activation of sensory brain maps between these adjacent brain regions, just as with phantom limbs. Indeed, brain imaging experiments on people with synesthesia have found that when they are shown only black-and-white numbers, the color areas of their brains are activated.

However, synesthesia is not limited to only seeing letters or numbers in colors. Some synesthetes report that not just numbers but even days of the week or months of the year are colored. Monday might be blue, Tuesday red, and Wednesday brown (or December might be yellow and March blue). What these variations have in common is the idea of numerical sequence or ordinality. This ability probably depends on another

part of the brain that is critical for the numerical concept (that is, 4 and IV are different physical symbols, but the idea that 4 is twice 2, half of 8, the root of 16, and so on, is the same).

Other synesthetes report that they feel tactile shapes when they taste things, and others report that they taste things when they hear words. For example, Richard Cytowic described a synesthete who feels tactile shapes on his hands when he tastes things. Chocolate mint feels like cool marble columns. Another synesthete, MB, reported the opposite—when he runs his hands through hamburger, he experiences a bitter taste in his mouth. Yet other synesthetes connect taste and hearing, for example, tasting lumpy mashed potatoes when they hear the word "London."

Still other synesthetes have told us that every number or letter has a gender (male or female) or personality (good or bad)—an exaggerated manifestation, perhaps, of the universal human tendency to binarize percepts and concepts into polar opposites (yin/yang, good/evil, up/down, heaven/hell, fat/skinny). Since thought and perception are inherently underconstrained activities, such binarizing may have evolved to permit a sequential division of a problem (as in a 20-question game) in order to achieve a rapid solution to the problem (through geometric progression).

How would our hypothesis explain all of these other forms of synesthesia? We do not have definitive answers yet, but we believe that what we have learned from studying grapheme-color synesthesia may help to explain these forms of synesthesia, too. First, we should look carefully at the brain basis of

these other functions, such as the neural basis of touch, taste, and hearing. The part of the brain involved with taste lies adjacent to the regions of the brain involved with hearing and the regions involved with touch, perhaps explaining why hearing can evoke tastes and why taste can evoke feeling tactile shapes. Second, we have to bear in mind that while it is *usually* true that adjacent brain modules are more likely to be connected to begin with and therefore more likely to be involved in cross-activation, even modules remote from each other often have *some* connection. This may explain why hearing causes synesthetes to see colors, even though these brain regions are far from each other. Explaining why some synesthetes experience genders and personalities for letters and numbers is more difficult, but may depend on connectivity between regions of the brain involved in perceiving objects and feeling an emotional response to them (as we all do when we see our mother's or father's face).

Synesthesia and Creativity

Numerous reports have suggested a connection between synesthesia and creativity. Oliver Messiaen, a famous composer and synesthete, described the influence of synesthesia on his creativity: "Colors are very important to me because I have a gift—it's not my fault, it's just how I am—whenever I hear music or even if I read music, I see colors." Postmodern British painter and synesthete David Hockney said, "I find that visual equiva-

lents for music reveal themselves. Certain passages seem to me all blue and green, and certain shapes begin to suggest themselves almost naturally." This is not a figurative statement, not a metaphor, nor an attempt to be creative. Every word is literal. In the case of David Hockney, music is color.

This raises the obvious question of why synesthesia is more common among artistic types—such as painters, poets, composers, and novelists—if, indeed, it is. According to one recent survey, as many as a third of all artists claim to have had some sort of synesthetic experience. What do these people have in common? They are all creative; they are very good at metaphor, at linking seemingly unrelated concepts in their brains. Furthermore, synesthesia runs in families. So if a person has the synesthesia gene expressed diffusely around the brain, he or she is going to have a much more cross-wired brain, creating a propensity toward metaphor, abstraction, and creativity.

One thing that artists, poets, and novelists have in common is that they are especially good at using metaphor—such as Shakespeare, who wrote in *Romeo and Juliet*: "It is the East and Juliet is the sun." It is as if their brains are set up to make links between seemingly unrelated domains, such as the sun and a beautiful young woman. When you hear "Juliet is the sun," you don't think, "Does that mean she is an enormous glowing ball of fire?" You know, instead, "She is warm like the sun, nurturing like the sun, radiant like the sun" or "She rises from bed like the sun, dispelling the gloom of the night." Your brain instantly finds the right links highlighting the most salient and beautiful aspects of Juliet. In other words, just as

synesthesia involves making arbitrary links between seemingly unrelated perceptual entities like colors and numbers, metaphor involves making links between seemingly unrelated "conceptual" realms. Perhaps this isn't just a coincidence. Perhaps the reported higher incidence of synesthesia in artists is rooted deep in the architecture of their brains.

The key to this puzzle is the counterintuitive observation that at least some high-level concepts are probably anchored in specific brain regions. Numbers are among the most abstract of concepts, yet even such an airy abstraction is represented in a relatively small brain region. If even concepts exist in the form of brain maps, then perhaps we have the answer to our question about metaphor and creativity. If some genetic factor were to cause excess connections between different brain maps, then depending on where and how widely in the brain the trait was expressed, it could lead to both synesthesia and to a propensity toward linking seemingly unrelated concepts and ideas. That is, creativity could be considered the result of hyper-connectivity between conceptual maps as opposed to perceptual maps—conceptual synesthesia. This would explain the higher incidence, perhaps, of synesthesia among artists, poets, and creative people in general.

The Emergence of Language

Throughout this chapter, we have been trying to move away from the idea that cross-activation is just an odd quirk in some

peoples' brains. Indeed, we are convinced it holds tremendous implications for understanding many aspects of our conscious human experience. We are all synesthetes to some extent. To demonstrate, Figure 2 shows two letters of an imaginary alphabet (intentionally unlabeled); one is kiki, the other bouba.

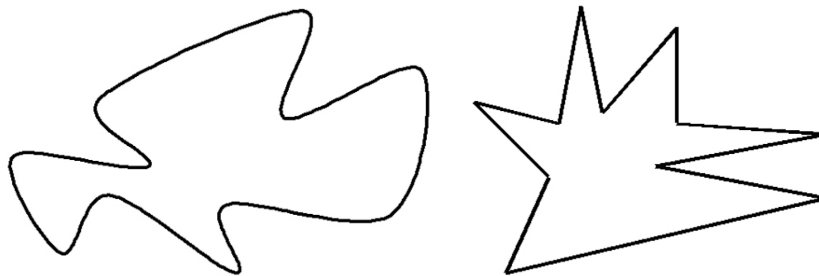

Figure 2. Which one do you think is kiki? Which one is bouba?

Ninety-eight percent of people in experiments say the jagged shape is kiki and the amoeboid shape is bouba. Why is that? Our hypothesis is that the gentle curves and undulations of contour on the amoeba-like figure metaphorically mimic the gentle undulations of the *sound* "bouba" as represented in the hearing centers in the brain and the gradual inflection of the lips producing the curved "booo baaa" sound. The waveform of the sound "ki ki" and the sharp inflection of the tongue on the palette likewise mimic the sudden changes in the jagged visual shape. This experiment suggests a deep connection between auditory and visual stimuli and suggests that these properties map onto each other in a nonarbitrary manner.

The sound and the picture of kiki have absolutely nothing in

common except for the single abstract property of "jaggedness" that is extracted somewhere in the parietal lobes of your brain—probably the angular gyrus. So you can think of this structure as performing a very elementary type of abstraction—extracting the common denominator from a set of seemingly dissimilar entities. We don't know exactly how the brain does this job, but once this ability to engage in cross-modal abstraction emerged, it might have paved the way for the more complex types of abstraction at which humans excel.

We suggest that this ability to make connections between sensory modalities might be the basis of the evolution of language. The bouba-kiki example shows there is a preexisting translation between the visual appearance of an object (represented in the fusiform gyrus of the brain) and its auditory representation (in the auditory cortex). Recent work in sound symbolism focuses sets of unrelated words beginning with similar sounds, such as /gl-/: "glow, glitter, gleam, glare" (the words are all related to light) or beginning with /sl-/: "slide, slink, slip, sled" (the words relate to liquidity and little friction). Words that start with /tw-/ ("twist, twirl, twiddle, twine") are often related to a twisty motion, with one thing going around another.

In addition to this cross-modal effect, there is also a preexisting, built-in cross-activation between the visual map in the fusiform gyrus and the motor Broca's area in the front of the brain that controls the activation of muscles in the lips, tongue, and mouth. Consider the example of words like "fu*dg*e," "tru*dg*e," and "slu*dg*e," in which the movement of the tongue on the palette actually mimics the "stickiness" and vis-

cosity of the seen or felt mud or chocolate (gradual adhesion followed by catastrophic release).

Finally, the hand area and the mouth area are right next to each other in the brain. A spillover of signals causes the echoing of hand movements by your lips, tongue, and mouth—a phenomenon much more prevalent in children than in adults—that we call synkinesia. When you want to depict something tiny you make a tiny pincer-like gesture opposing your thumb and forefinger and notice that your lips do the same when saying "teeny weeny" or "diminutive," synkinetically mimicking your fingers. Or when you beckon someone to come toward you, you stick your arm and hand out, palm up, and then flex your palm and fingers towards yourself, a gesture that the tongue mimics on the palette when it bends gradually backwards before hitting the roof, while you say "hither."

So now we have three things in place: hand to mouth; mouth in Broca's area to visual appearance in the fusiform gyrus and auditory cortex; and auditory to visual, the bouba-kiki effect. Each of these is a small effect, but together they create a synergistic bootstrapping that leads to an avalanche, culminating in the emergence of language.

Conclusion

Scientists have begun to approach questions concerning the malleability of the adult human brain and even the neurology of metaphor and creativity. Here we have simply illustrated

these principles by describing two phenomena that demonstrate the malleability of the brain (phantom limbs) and the importance of our understanding of neural connections for understanding larger issues such as creativity, metaphor, and even the evolution of language.

The questions for educators are, “How can we tap the mind power that anomalies such as those described above show is within us?” and “How do we maximize individual potential?” These questions have not yet been answered. We believe, though, that by training students in poetry, metaphor, art, and humor we will help shape more creative and imaginative human beings—skills that may very well spill over into other areas of the brain.

It is a unique privilege for our generation—and our children’s—to witness what we believe will be the greatest revolution in the history of the human race: understanding ourselves as we transform our understanding of the human brain.

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