TODD HARGROVE

Body Maps

This talk is about body maps, which are the neural structures used by the brain to sense where everything is and to control the movement of the body. This is one of the most important concepts I've learned that helps me help people move and feel better. This concept is always on my mind when I'm working with a client. This is something that probably has a lot of practical value for any therapist or trainer working with someone to try to improve their movement. It's a totally fascinating subject in its own right, aside from its practical value, and I hope you enjoy the talk.

I'll start by reviewing the familiar idea of proprioception, which means body sense or kinesthetic awareness. You can look at these terms as having slightly different meanings. Some people do and some people argue whether there's any difference between them, but for our purposes, I'm going to use these terms interchangeably.

Proprioception, body sense or kinesthetic awareness all refer to the brain's ability to sense the position and movement of the different body parts through space. Because of proprioception, you can move your body very accurately without having to watch yourself. You can touch your hand to your nose with your eyes closed, walk without watching your feet and do all these amazing things.

When your proprioception is compromised from a neurological disease or if you're drunk, seemingly simple activities like walking or standing can become almost impossible. It should be easy to see that any coordinated movement depends on having a good sense of where your body is and what it's doing. Elite level movement, in sport or dance, requires an elite level of proprioception, at least in regard to the movements that will be performed.

If you imagine a gymnast doing a back flip onto a balance beam, it obviously stands to reason she has an incredibly good sense of where her feet are, even when they're over her head. This is something a normal person like me probably doesn't have at all because we haven't spent very much time in that situation.

Proprioception, or body sense, depends entirely on the body maps in the brain. The body maps are the physical parts of the brain organized in such a way as to represent all the different body parts, the way lines on a map represent roads.

Each part of your body has a separate area of the brain dedicated to moving and sensing that body part. We have hands, and we have virtual hands in the brain. These are parts of the brain where the neural structures are set up to represent the size, shape and position of the hands.

The brain will even devote a little space to representing objects that aren't part of the body, but we use them almost as if they are. For example, a tennis racquet will start to get represented in the brain of a player so the player is able to hit the ball. Another even sillier example is a large cowboy hat that you wear all the time, and the brain will start to represent where that is. That's why you'll know you need to duck when you go under a small door frame.

How do these virtual bodies in the brain communicate with their actual counterparts? It happens through the nervous system. There are millions of microscopic end organs located all throughout the body called 'mechanoreceptors.' They're in the joints, the skin and the muscles. Whenever they're tripped or triggered by a mechanical force, they send a signal to the brain. The brain gets a massive amount of signaling every second; it processes all this information and creates numerous maps so it knows exactly where everything is in the body. That's what it uses to decide how to move.

Because the brain needs to use the maps in order to make decisions about how to move, the quality of the map will help determine the quality

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of the movement. If you have a very detailed map of a certain area of a certain body part, you're going to be able to make precise movements.

However, if the map is unclear or fuzzy, you're not going to be able to make precise movements. Part of the reason we know this is because the body parts that have greater movement demands actually have bigger maps. You can see this on a MRI. For example, your hand is capable of extremely intricate and differentiated movements and sensations. Consequently, the brain devotes a very large area to sensing and controlling it.

By contrast, the brain doesn't devote quite as much space to mapping areas that don't have very large movement or sensation demands, such as the middle of your back or your elbow. Just as you would need a very large and detailed map to get around New York City compared to a small city in Iowa, you need a much bigger and detailed map to use your hand than to use your elbow.

If you drew a picture of the human body with each body part being the size of its virtual counterpart in the brain, it would look completely hideous. It would have really large lips and a tongue. It would have really big hands and feet. Everything else would be really small. If you want to know what this looks like, you can do a Google image search for the word 'homunculus' and you'll see a homunculus. It's this little guy with a huge face and huge hands.

Another indication we have that good maps are essential for coordination is they grow larger when placed under demand. The part of the musician's brain that senses and controls the fingers is observably larger than the counterpart of someone who doesn't use their fingers quite so much. Another example would be someone who reads Braille. They have incredibly sensitive fingertips. It's because the maps in the brain are much better and more detailed than the average person's.

How do we build the maps and become better able to move as a result? The information necessary to maintain and build the maps is provided by mechanoreception from the body, which happens when we move.

You can sense the effects of mechanoreception on the quality of your maps by doing a simple experiment. Try to imagine the exact position of your left clavicle—your collarbone. Try to imagine exactly where it attaches to the sternum, and then in your mind's eye trace the arc it makes as it goes over to the shoulder joint. Just get a basic sense for your ability to imagine where that is.

Now take the fingers of your right hand and trace along the bone where it attaches to the sternum. You can feel it as it arcs over to the shoulder. Just go up and back a few times and trace its outlines. Take your hand away and then re-imagine where that is in space. Compare that to how well you can sense where the right clavicle is. You will probably notice it's much easier for you to sense exactly where the left clavicle is compared to the right. That's because as you touched it, you stimulated the mechanoreceptors there. They sent some signals to the brain, to the maps that govern the clavicle and, for at least a few instants, that map was lit up by a little neural activity. Then it was easier for you to sense where the clavicle is.

That's only temporary, of course. In order to make long-term changes in your body maps, you need to place demands on them consistently over some period of time. When a certain movement is used repeatedly in a coordinated way, there are actual physical changes in the part of the brain that controls that movement.

Now, let's talk about how your maps can degrade a little bit or get fuzzy. It's exactly the opposite process. While movement tends to clarify maps, fill them out and give some good detail, the lack of movement will tend to blur them.

There's a famous experiment where researchers sewed together three fingers on a monkey, so all of those fingers had to work as one unit. Then, after a little bit of time, some MRIs revealed the mapping for those fingers were one unit in the brain. If three fingers become one in the actual body, three fingers are going to become one in the virtual body of the brain. As far as the monkey is concerned, it's not able to have differentiated control between the

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fingers because after a while, it wasn't getting any differentiated information about what those fingers could do.

This is the neural version of the 'use it or lose it' principle. It's sometimes called "sensory motor amnesia,". This means, if you don't use a movement for a certain amount of time, you will forget how to make that movement. As a practical matter, it will be impossible for you to make it, even though it physically should be possible.

One area where it's very common to have sensory motor amnesia is the pelvis and low back. In many people, especially people who do a lot of sitting, which is almost everyone, there's not a lot of differentiated movement here, and the area tends to move as one big block. That's not necessarily because the area is one big block structurally or the tissues aren't capable of movement. It's because in the brain the area is represented as one big block. There's no differentiated movement possible in that area, not because the structure doesn't allow it, but because the movement has been neglected for so long, the brain no longer maps it.

Another way to lose the quality of your body maps is pain. This has a little bit to do with the idea of sensory gating. Sensory gating means the processing and perception of a particular piece of sensory information is reduced a little by the presence of competing sensory information. This is also called the 'cocktail party effect,' somewhat like what happens at a party. There's auditory information in the air, but your brain is tuned in to only one particular conversation. Because of that, it doesn't hear anything else going on around you.

At any one time, your brain is bombarded with a massive amount of information from multiple sources. The ears are picking up auditory information. The eyes are picking up visual information. Your body is sending mechanoreceptive and nociceptive signals to the brain. The brain can't possibly pay attention and process all of it, so it tends to filter out anything it considers redundant or not so interesting and important at a particular time.

Now, one piece of information from your body the brain is likely to consider pretty important is nociceptive information. This is information coming from free nerve endings, which indicates there might be some tissue damage or some danger signals in a particular area. You can call these pain signals, but I think it's better to call them danger signals. If a particular area is injured, there's nociceptive signaling from that area. Then, any mechanoreceptive information also coming from that area will tend to get filtered out, because the brain might not consider that to be quite as important.

If your knee hurts, you're getting nociceptive information from the knee, and the brain is going to spend less time paying attention to any mechanoreceptive information from the knee. As a consequence, the maps for the knee—the movement maps—are not going to be fed as much because there's a reduced amount of mechanoreceptive information. Another reason pain tends to degrade the quality of your maps is, if something hurts, you're going to start reducing the amount of movement in that area. That's another reason the brain doesn't get as much mechanoreception from there: Use it or lose it.

If you're in pain, there are certain movements you're going to start neglecting and you're going to lose them as far as the brain is concerned. Pain and injury in an area can cause a vicious cycle of loss of coordination and more pain. This is why you might repeatedly sprain the same ankle. Pain can tend to degrade your maps, and that works both ways. If you have problems with your maps, it's possible this could in itself cause pain.

The most dramatic example of this is phantom limb pain. Many people with an amputated limb experience pain where the limb used to be. Even though the missing limb is gone, the virtual limb in the brain lives. The space is still there and the neurons can be stimulated by cross talk from nearby neural activity.

When a particular part of the brain is not getting stimulated by its normal input, other parts of the brain can start to cannibalize and grow like dandelions in a yard. That part of the brain can start to be stimulated by nearby neural activity. If

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this occurs in a phantom limb, you end up with the sensation that the limb is there, and it feels incredibly realistic. It feels exactly like a real limb. Often, unfortunately, the experience of the limb can be incredibly painful.

There is a very amazing treatment invented by Ramachandran for phantom limb pain that works sometimes. There are books on this, and you may have seen TED talks about it. What they do is to place the remaining limb inside of a mirrored box in such a way that when the person looks at the mirror, it looks like the lost hand. Moving the hand a little creates an illusion that tricks the brain into thinking the missing limb is alive and well. This can help with the pain. It's kind of an amazing example of how the health of the virtual bodies is just as important as the actual bodies.

There are many other interesting examples of how pain can be the result when the brain is confused about the signals it's getting from the body. One of these comes from what's called the "thermal grill illusion." The way this works is, you stick two of your fingers—your pointer finger and your fourth finger—into cold water, and the middle finger in warm water. For some reason, this is an unusual situation that tricks the brain into thinking the middle finger is in very hot water, and you can feel pain in that finger as a result. There's no actual damage, but because of the confusing situation, the brain gets threatened and causes pain.

Another interesting illusion they've studied is what's called 'the rubber hand illusion.' This involves taking your left hand, putting it out of sight, so it's behind a screen and then putting a rubber hand where the left hand would normally be, right next to the right hand on a table. The researcher strokes the existing left hand behind the screen with a little object and uses the same object to stroke the rubber hand.

What you see is the rubber hand being stroked while you feel actual stroking information coming from the hidden left hand. This gives rise to an uncanny illusion where the person takes ownership of the rubber hand. In fact, if you threaten to hit the rubber hand with a hammer, the person would flinch.

There's another fascinating aspect of this experiment. The hidden hand, the left hand behind the screen, actually becomes colder after the brain takes ownership of the rubber hand. It's almost like once the brain stops recognizing the left hand is actually part of the body, it changes the way it regulates that area.

This shows the brain's representations of the body parts can have significant and even immediate effects on the physiological processes related to those body parts. There are some real links between how the brain creates an image of a body part and what will happen physiologically in that body part. This can affect the blood circulation in that area. We might speculate it can even affect the way the immune system works in that area.

There are other studies showing people with chronic pain conditions such as fibromyalgia are more subject to these illusions than other people, and some of these illusions can actually cause pain. There are other studies showing that giving these people some sort of corrective sensory information, which will cure the illusion, will actually cure the pain, as well.

On the basis of all this interesting evidence, there are many pain researchers who believe inaccuracies in body maps play some role in chronic pain conditions. Some believe that giving appropriate sensory information to cure the inaccuracies in the body maps is a potential way to treat chronic pain.

I hope all of this information is convincing you that the health of your brain's virtual bodies can be just as important as the health of the actual body parts.

What can we do with all of this information? For me, all of this has several implications about how we should try to improve movement. It also indicates how we should go about eliminating pain with movement when we're doing some sort of intervention, whether that's massage, joint mobility drills, stretching or corrective exercise.

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I have a list of considerations.

The first would be to recognize that the body maps should be a primary target of whatever type of intervention you're doing. The way you hit that target is by providing information to the brain in a way it's likely to be able to hear, process and incorporate it. How do we make sure to hit that target?

The first way is to avoid pain as much as possible. I discussed the idea that nociception and mechanoreception compete for the brain's attention. The more nociception there is, the less the brain will be able to pay attention to mechanoreception and the less map enhancement you're going to get.

If you're practicing a skill, doing a joint mobility drill or getting a massage and there's pain during the process, a lot of the benefits will be lost because the brain isn't going to be able to pay attention to the beneficial information you're trying to send. Along the same lines, be mindful and attentive to what you're doing when you're moving. The brain receives a massive amount of sensory information each second and it's not going to attend to all it wants. It has to be selective in filtering out things it considers to be redundant, useless or not interesting at the particular time.

At any time there are a lot of noises, you don't really hear unless you pay attention—cars going by outside, birds chirping or maybe your wife telling you to get some housework done. Just because the information is coming in, doesn't mean it's being processed. Just because you're moving, doesn't mean your brain is paying attention to what's going on. Don't just go through the motions. Really pay attention to how you're moving. That's part of what makes quality practice.

A third suggestion is if you're doing movement practice and you want to get your brain's attention, using a novel movement or one that provides a novel stimulus is more likely to do that. Most joint mobility drills or body techniques actually work a little bit on this basis. They incorporate novelty already, and that's why they work. Part of the reason foam rolling works or a massage technique works is this mechanical stimulation in a particular body part is unusual. It's not something the brain gets in normal everyday life.

That information can be useful to the brain in getting a better understanding of what's going on in that joint. However, part of what this means is, endlessly repeating the same drill, the same foam rolling or the same activities will tend to have diminishing returns simply because novelty wears off and there will be less stimulation. You might want to change things up with your movement routine to make sure your brain stays interested.

One caveat on the novelty idea is the movements you do or the information you send to your brain has to be relevant to some functional task to be useful. It might be novel to go roll in Jello or squat on a Swiss ball, but the functional relevance of those activities are such they're not likely to lead to reorganization of how your body wants you to move. There has to be some sort of tethering to reality.

One example of how you might do that is to take a basic squat pattern—maybe it's giving you problems in a vertical stance. Try the same pattern on your back or in a crawling position where you can duplicate some of the same lower body flexion movements, but in a slightly different environment. This is a similar, but different principle a lot of coaches apply to deciding what kind of exercise or movement to do.

On this issue of repetition versus novelty, there's yet another competing consideration. Sometimes a lot of repetition is necessary to make temporary changes permanent. Part of the way we make permanent changes in the brain is practice, practice and practice.

There are studies that show you can measure changes in the finger maps day by day when learning how to read Braille and developing the finger maps to do so. One study measured the maps on Monday. They'd train the subjects to learn Braille until Friday. By Friday, they'd have bigger finger maps.

Interestingly, when they took a couple of days off and came back on Monday, their maps had shrunk back down to normal size again, so there's

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a regression. Yet as they practiced, practiced and practiced—I believe this was after six to nine months—these changes in the map size became much more stable.

The researchers hypothesized that the difference between changes in the temporary maps versus changes that were more stable was the temporary changes involved strengthening the quality of existing neuronal connections in the relevant body maps. The more stable, permanent changes involved actually developing new connections, which is a process that takes more time and repetition.

If you ever notice temporary changes in your coordination or some other quality of your movement through some sort of intervention, maybe you need to repeat, so the changes turn into more stable body map alterations.

Another very basic principle this body map knowledge gives us is that slow movement is a potentially beneficial way to fill in gaps in movement maps. That's for a number of reasons. The slow and gentle movement of Feldenkrais, Tai Chi, the Alexander Technique or in certain forms of massage are less likely to cause pain. They're more likely to allow us to find movement angles or certain movements we might miss at higher speeds. They can cut down on the amount of noise or irrelevant sensory information that comes with movement.

Let's say you want to map the shoulder in the brain. If you move the shoulder very slowly and precisely, you're going to cut down on the amount of muscular activation happening in other parts of the body, which will tend to distract the brain from the signal. The signal you want to send is, "This is exactly what's going on in the shoulder joint." You can make that signal easier for the brain to hear by minimizing noise from other areas.

There's another interesting principle called the "Weber-Fechner Rule," which says the brain's ability to discriminate between the magnitude of two particular stimuli is going to be much greater when the amount of the stimuli is lower.

If I'm holding a one-pound plate in my hand, it's going to be very easy for me to know if you add an additional pound. I can feel it's heavier. If I'm holding 200 pounds, which I probably couldn't do, and you add an extra pound, I wouldn't notice any difference at all.

When you move very slowly and with less force and with less muscular activation, it's going to be easier to discriminate in the amount of effort it takes to get that movement done. When you move as fast as you possibly can, your ability to discriminate is less, which means the detail in the map is also less. Whenever you're struggling with a particular movement or there's a certain area you want to re-coordinate, especially if you think there's some sensory motor amnesia or there's been a previous injury, working very slowly in that area can be a good way to redevelop the maps.

Just to review a little bit and sum up. When you're doing any form of intervention to try to improve movement skill, keep in mind the primary way you'll be doing that is giving the brain information. Coordination in movement skill lives in the brain. The brain builds that skill based on the information it gets from the body. You want to provide interesting, quality information in a way that gets heard and processed.

Choose non-painful movements—interesting, functionally relevant movements that provide a high signal-to-noise ratio. Then, repeat those movements so you're sending the information long enough and as many times as necessary to make a permanent change.

If you'd like further information, you can go to my website, *bettermovement.org*, where you'll find a lot of articles on the same topics.

If you're looking for a book to learn more about this, there's an excellent book by Sandra Blakeslee called *The Body Has a Mind of Its Own.* I also recommend a book by Norman Doidge called *The Brain That Changes Itself.*

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