The Brain's Experience Of Extra Body Parts

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> "This theory goes as follows … All brontosauruses are thin at one end, much, much thicker in the middle, and then thin again at the far end. That is the theory that I have."
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> — "Theory On Brontosauruses By Anne Elk", from *Monty Python's Flying Circus*

The recent debut of **polydactyl66**, a girl gamer with six fully-developed, fully-formed, individually-controllable fingers on each hand, no doubt raises the obvious question in everybody's mind: what's it like to experience having, and using, such extra functional body parts? It seems to be something that is impossible to imagine by those who do not have them, and the possessor of such unusual anatomy can give no more than hints as to the nature of the experience.

One point, though: such a phenomenon may be somewhat more common than our gamer girl Poly and her admirers assume; there is a Da Silva family in Brazil, 14 of the 26 members of whom were born with six fully-functional fingers on each hand. And looking closely at the structure of their hands and the idiosyncrasies of how they use them, I see remarkably close resemblances to those of polydactyl66 herself — there is definitely a common pattern here. Suffice it to say that the extra digits can have their (minor) downsides. But that's a separate issue to what we are discussing here.

Anyway, after thinking about this for a bit, I have come to the conclusion that it **is**, in principle, possible for someone with more conventional anatomy to imagine what such additions would feel like. I am not going to develop the method in detail, but I will sketch out some thoughts on characteristics of the brain and nerve wiring that might lead to such a technique.

Caveat: I am no expert on anatomy or physiology, or neurology for that matter. These are just my thoughts, based on my layperson-level readings on these subjects. The discussion may seem too long-winded and technical for some, yet not technical enough for others. What I say may be misleading in some parts, completely wrong in others. I'll leave it to the experts to figure that out.

First of all, let me state one fact I am quite sure of: Poly has **no** extra parts of her brain wired to her extra fingers. There are **no** unusual features at the brain end of her nerve wiring that are related to this feature of her anatomy. **Her ability to sense and control her extra appendages comes down to the natural plasticity inherent in every normal human brain** — and that includes yours and mine.

An Introduction To The Human Nervous System

The human nervous system is made up of nerve cells, the technical term for which is *neurons*. Each neuron has a long extension — think of this as the main "wire" that conducts nerve impulses, if you like — called the *axon*, and a bunch of short extensions on the opposite side of its *soma* (main body) to the axon, called the *dendrites*. (Figure 1.)

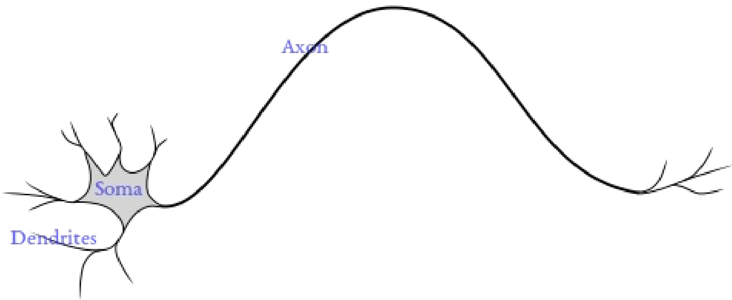

Figure 1: A neuron

When these dendrites lie adjacent to the axon of one or more other neurons, the junction formed is called a *synapse*. Synapses may be thought of as the "logic gates" of the nervous system. The nerve cells do not actually make physical contact with each other at a synapse: instead, impulses are propagated across the gap with the aid of a class of chemicals known as *neurotransmitters*.

The direction of nerve impulses is inherently one-way: a neuron picks up a stimulus on its dendrites, which causes a pulse to go out on its axon, which might in turn cross a synapse to stimulate the dendrites of another neuron.

An important point is that **the vast majority of synapses occur in the brain**. There are synapses elsewhere in the body, in structures called "ganglia" which have to do with unconscious reflex actions, and also with collecting sensory information for transmission to the brain. But certainly for *voluntary* muscle control, and for conscious reception of sensory data, all the important connections are made in the brain.

Every single one of these nerves connecting the brain with the rest of the body is a bundle of axons belonging to neurons whose main bodies are located either within the brain itself (for "motor" neurons, for sending control signals to muscles and the like), or at the opposite end (for "sensory" neurons, for receiving information from your sense organs). Think about that: neurons are cells in your body that can each be over a metre long.

So, from the brain, individual axons (nerve fibres) get bundled up into nerves. Those connecting parts of the body other than the head become part of the spinal cord, going down until they reach a suitable point to exit the backbone and be separated off into a smaller bundle, which in turn might separate off again some distance on into further, smaller bundles, and so on until they get down to the endpoints.

To recap: in terms of voluntary muscle control, there are no “switching stations” outside of the brain: every axon in every nerve bundle represents a direct end-to-end connection between some point in the body and some point in the brain.

Consider for example the nerves going to the finger muscles. Most of these are actually located in the forearm, not the hand itself; you can feel on the back and front of your palm the tendons that connect between these muscles and your fingers. Each finger has multiple muscles controlling it, but let us oversimplify things by only considering one muscle per finger. For someone with the usual 5 fingers on a hand, a nerve bundle might split into 5 smaller nerve bundles, each feeding one finger muscle. Also for clarity, we will draw only a few nerves, and will draw the nerves extending all the way into the respective fingers, rather than stopping at the actual finger muscles. (Figure 2.)

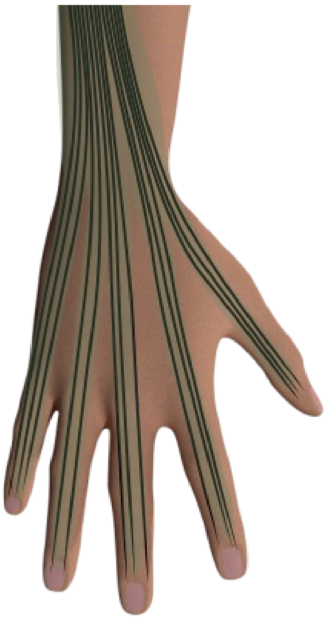

Figure 2: Oversimplified illustration of a fixed number of nerves distributed among 5 fingers.

For someone with 6 fingers on the hand, the nerve bundle splits 6 different ways to drive the corresponding number of finger muscles. The total number of axons in those bundles will be similar in both cases, so the more you split the bundle, the fewer axons end up in each sub-bundle. (Figure 3.)

Figure 3: Oversimplified illustration of the same number of nerves distributed among 6 fingers.

So what does the wiring for these nerves look like at the brain end? What I believe happens here is that **there are no predefined areas corresponding to specific finger muscles**. Instead, the individual neurons from the nerves connect through to two large areas in each half of the brain: the *sensory cortex* (the termination points for the incoming sensory nerves), and the *motor cortex* (the connections for the outgoing motor nerves). There may be some rough, broad structural divisions in each of these at, say, the limb level and other such major body regions. But there is nothing so hard-and-fast at the lower detail levels; instead the brain actually has to *learn* to configure itself to accommodate the specific nerve wiring that it finds itself connected to. (Figure 4.)

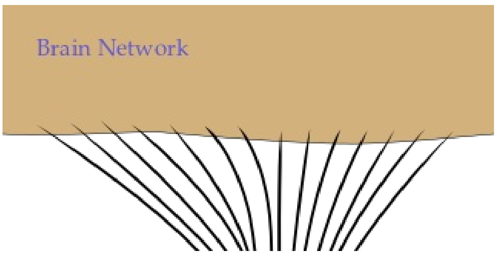

Figure 4: The other ends of those same finger nerves (oversimplified illustration) — note the lack of differentiation of the actual brain structure at this level.

Thus, for motor nerves, the brain has to learn to control the firing of the outgoing impulses finely enough to activate particular muscles, and not others. You see this effect in a newborn baby, as they thrash around their limbs in an uncoordinated fashion; over time, their movements become better managed, as the brain figures out what all the connections do.

In somebody with 5 fingers (Figure 5) on a hand versus one with 6 (Figure 6), the *same* overall area of the motor cortex is responsible for the finger muscles, but over time, with practice, it refines the choreography of the firing of its sections differently to deal with the different numbers of muscles.

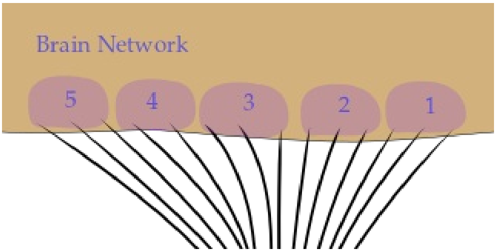

Figure 5: The same brain structure configured for 5 fingers — patches indicate clusters of neurons that have learned to fire together, numbered by corresponding fingers.

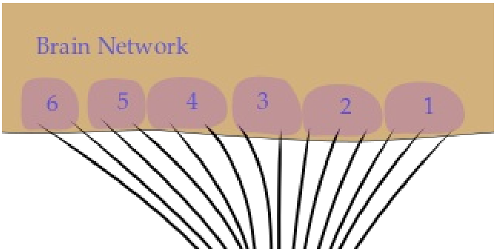

Figure 6: The same brain structure configured for 6 fingers — patches indicate clusters of neurons that have learned to fire together, numbered by corresponding fingers.

A corresponding situation applies to sensory nerves, bringing information into the brain. There is nothing attached to each incoming sensory nerve connection indicating precisely where in the body it comes from, so the brain has to learn these locations and build up a mental image of where each nerve ending is located. What is significant is, this learning is not permanently burned into the brain: it can be (at least temporarily) “fooled” into adopting a different mental image, as has been demonstrated in well-known experiments such as the “rubber-hand illusion”.

However, since sensory nerves start growing from the extremities, more extremities would seem to mean having more sensory nerves. But since the total number of nerve fibres connecting the brain with the rest of the body is on the order of hundreds of thousands, a few thousand more coming from a few extra fingers or toes are probably easily accommodated in the formation of the major nerves.

Taking It Further

The above discussion could in principle be generalized to more major body parts, such as entire extra limbs. But this raises more unanswered questions, not least because real-life occurrences of individuals with such characteristics are somewhat rarer. Also information as to how much control they have over their additional appendages seems a bit sketchy. How plastic is our brain structure on such larger scales? What is the limit to how small a cluster of neurons can be for operating each muscle? What happens below this limit?

Also, consider certain forms of conjoined twins. Look at *dipygus* — doubling of the lower half of the body, for example the case of Myrtle Corbin. Presumably, she had more or less the usual number of muscle nerve fibres growing from her brain. How did they divide themselves up among her doubled lower parts? Did each part end up with half the usual number? Did she have double the number of sensory nerve fibres coming from those doubled lower parts? Did all of those find their way into her brain? Or did some stop short?

Missing Pieces

What about those who are lacking part or all of one or more of the normal complement of limbs? How do their brains adapt?

First of all, let us distinguish between *congenital* amputeeism — those who are born missing limbs — and those who undergo amputations of parts they were born with, later in life. Because the latter would start out with a reasonably normal configuration of their nervous systems, parts of which are then lost as part of the amputation.

When a limb is removed, the nerve fibres are also severed. What happens to the parts that are left? For the nerves that control muscles, the main bodies of the cells are still intact, it was only parts of the axons that were cut, so presumably they can survive, even if they no longer have a function. Or do they atrophy if they are not stimulated? While for the sensory nerves, the nerve bodies are lost. Does that means the remaining severed axons die? These questions have implications for attempts to restore amputated limbs, whether through sophisticated prosthetics that interface to the nervous system, or via transplants.

Then there are those for whom certain limbs simply failed to develop in the womb, for a variety of reasons, many of which remain poorly understood. As with the case of extra appendages, the number of nerve fibres coming out of the brain to control the muscles should still be the same. But where do they go? If they simply terminate at the base of where the missing part would go, with no function to perform, do they survive? Or do they waste away?

What about sensory nerves coming from the extremities? If an entire arm is missing, does the region of skin covering the area where the arm would have been have the same number of sensory nerves as the missing arm? Or does it have fewer, commensurate with a similar area of skin at the base of the arm if it were present?

As I understand it, amputations can also occur in the womb, for example because the placenta gets wrapped around a developing limb, constricting and eventually severing it while the cell structure is still soft and pliable. Depending on how much of the nerve structure has developed, this might be considered to be an in-between situation, sort of a mixture of the above two.

Also consider the case of *dicephalus* conjoinment — a “two-headed” person, such as Abby and Brittany, the Hensel twins. To me, this is not that different from two people each of whom only develops half a body in the womb. The fact that they are joined together seems to make little difference to anything that is relevant to our discussion here: if there were some kind of interconnection between their nervous systems, that would add an interesting factor, but as far as I know nothing like this has ever been shown to happen.

So What Does This Mean?

The brain is a wonderful learning machine. Normally, most of its adaptation to body configuration happens when the individual is very young, but there are indications that a lot, if not most, of this plasticity carries over into adulthood. So if the brain can learn to adapt to one body configuration, it could also learn to adapt to another.

So, in principle, it should be possible to make various kinds of augmentations to one’s body structure, and become accustomed to the new configuration. Beginnings are already being made today in terms of cybernetic nerve implants and limb transplantation, mainly to replace lost body parts. But they could also be used to add new ones. And in future instead of getting organic parts from donors, we might be able to grow our own, from our own body cells.

But, in lieu of access to such as-yet-unrealized technological innovations, what about trying to synthesize, purely out of one’s imagination, the experience of additional bodily appendages? Can that ever come close to the reality?

Yes, with sufficient practice I think it can. All the clues as to how to proceed are given above: it is simply a matter of redefinition of the existing capabilities of your brain, of reinterpretation of your existing mental experience of your body.

It’s all in the mind, you know.