Reflecting on Motor Cortex and Its Place in Developmental Care

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Organisms, by definition, are made of interconnected organs that perform specific functions. Here we focus on one particularly magnificent organ – the brain. The human brain is an organ that makes a variety of products. With receptors tuned to the world outside the body, the brain makes percepts such as colors, temperatures and tastes. Other receptors tuned to the world inside the body, stimulate the brain to create sensations such as hunger, thirst, and fulfillments. The brain metabolizes experiences and produces thoughts. It secretes emotions. Yet, the majority of the processing of the nervous system is involved in making *movements*.

Movement is the stuff of behavior. And behavior is the stuff of NIDCAP. To make a NIDCAP observation is to see a world of movements on multiple levels, all manifested by a baby organism.

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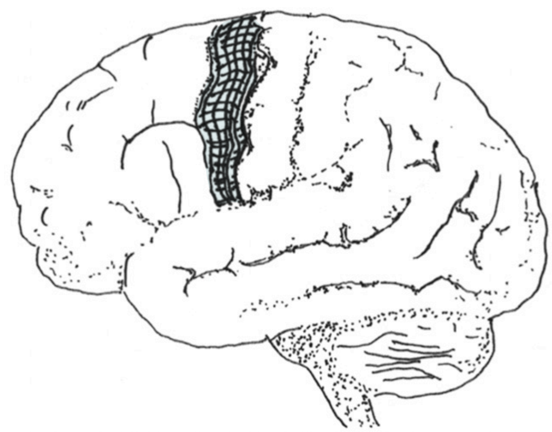
Synactive theory delineates movements in three domains: motor, autonomic, and regulatory.[1,2] The motor domain comprises limb movements and other actions that are typically tagged as "behavior". But the autonomic functions that we observe are also behavioral movements: respiratory movements of the diaphragm and beating movements of the heart muscle, for example. Similarly, the regulatory domain is full of movements: those of muscles that alter facial expression and flare nostrils, as well as the tiny muscles that can modulate skin tones which signal changes in state. Synchronies among limb movements, heartrate, and breathing function as a total regulatory dynamic. Together, we use these movements to recognize and interpret "the voice of the infant".

The goals of developmental care are served by our understanding of the movements that constitute behavior, for this is our window on the states, status, and progress of a baby. To understand better, we must ask: What neural structures and organization constitute the motor system?

In its neural organization, the adult human motor system is both hierarchical and distributed. Top billing goes to the primary motor cortex (also known as M1) which occupies a prominent region of cerebral cortex. M1 arches from one side of the brain to the other like the headband of a pair of headphones. Figure 1 depicts the band of M1, just anterior to the Central Sulcus.

Figure 1: Drawing of adult brain showing location of M1, or Primary Motor Cortex *(cross-hatched area).*



The cerebral cortex is one sheet of cells comprising six layers. The sheet is crumpled together to fit within the skull, thus creating the ridges and valleys (gyri and sulci) defining the human brain's appearance. There's a spatial representation of the body along M1's surface. Head and face occupy the most lateral positions; the rest of body is represented along M1 in orderly fashion, creating a map of what is controlled where.

From Layer V of primary motor cortex (M1), axons of the large, "pyramidal" neurons gather to form the *corticospinal tract* (CST) which extends down into the brain and beyond. The CST contains the longest axons in the central nervous system, reaching from cortex to the sacral spinal cord. This white matter (myelinated) tract is not a simple 'straight shot' to the base of central nervous system. For many of the neurons, there are terminals and loops within the brain. These include connections in the subcortical basal ganglia and the thalamus. Along its path, the CST also connects in the hindbrain (pons and medulla). It gets inputs from cerebellum, one of the brain systems that contributes learned patterns of movement control.

At each vertebral station along the spinal cord there are neural circuits arranged so that they fire in patterns that create organized muscle movements. Some of these movements appear as simple "reflexes", others as more complex sequences that may move a hand to grasp or a foot to withdraw. The CST and its inputs orchestrate and coordinate the spinal components to create adaptively organized voluntary behaviors.[3]

Importantly, M1's control of the muscles of face, mouth, tongue and eyes is organized similarly in and on the way out of the cortex, but has a separate name - *corticobulbar tract* (CBT). The CBT emanates from cortex via the same type of Layer V neurons described earlier. The two populations (CST and CBT) are bundled together subcortically in the brain where they give and receive connections as they traverse to mid brain. The CBT group departs in the hindbrain. There it connects with nuclei of the cranial nerves. This is an ancient array of sensory and motor nerves that serve the anterior end of essentially every organism that has a front end and is bilaterally symmetrical! In humans and other organisms that have a face, the same organized array of cranial nerves are at work. The CBT axons go no further, but they are in charge from the neck up.

Following this ultra-brief characterization of the *adult* motor system, we can turn to some stunning new findings about the development of M1. This new knowledge requires some radical re-thinking, but I believe it has a lot to say about babies in the NICU and about developmental care, so it's worth digesting. Note that the results covered in this discussion apply similarly to humans and a variety of non-human animals.

Let's start with one of the major findings: Early in postnatal life, M1 does *not* control movements! Is this because M1 is too immature to function and is thus "silent"? No, M1 neurons fire in orderly, lawful, functional ways. But its neuronal activities do not produce movement. Instead, M1 neurons in the infant organism fire *in response* to movements. This was discovered in the lab of Mark Blumberg (University of Iowa), a prominent infant sleep neuroscientist. Blumberg and his associates have been carefully observing sleeping infant rats, specifically the "twitches" made regularly by their paws and limbs during "active" sleep, often called REM sleep.[4,5] They have mapped the impulses going from the limbs to the brain and from the brain to the limbs. Blumberg and his associates discovered that the infants' spontaneous (unprovoked) twitches aren't preceded by brain activity; instead, M1 responds to the movements.[6] That is, M1 senses the movements – from receptors in the limbs, the skin, or both. Simply put, during early infancy M1 is sensory cortex, not motor cortex!

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In identifying M1 as a functional sensory cortex before becoming primary motor cortex, Professor Blumberg sees M1's sensory function as the brain's way of acquiring a map of its body, perhaps learning the 'feel' of the movements of each joint, minor appendage, and limb – and guiding the wiring and sculpting of an accurate cortical map of the body it will come to control. The idea that sensory experience regulates, and shapes neural architecture is supported by examples in other sensory systems.[e.g,7,8] The transformation from sensory-to-motor function in a major cortical area is a stunning finding, challenging long-held ideas about developmental continuities and some traditional uses of behavioral measures for inferring cognitive processes.[9]

We also have to ask, if M1 in the infant is sensory and not motor cortex, what controls the young infants' movements? The answer attests to the capabilities of the basal ganglia, associated subcortical, hindbrain structures, as well as cerebellar and spinal circuits that comprise the motor system. Lack of motor inputs from cortex probably explains the absence of fine motor control that typifies early infant movements.

These new findings have many implications pertinent to developmental care in general and to NIDCAP practice in particular. If the motor behaviors of young infants are controlled subcortically, does this mean that their movements are expressed without conscious awareness and thus lack agency or intent? Does this make them meaningless, automatic, reflexes? To such questions and concerns, I believe the data say "no!" All evidence indicates that regardless of 'how' an infant's movements make and maintain contact with the mother, they are in contact with her body, at which point they can derive all the marvelous benefits of contact behavior. In the animal world, think of infant monkeys, reflexively grasping and holding the fur of their mothers as they amble or climb. These "mere reflexes" serve their purpose. Babies stay warm, protected, and repeatedly engaged in prolonged contact interactions with the mother. They are exploring her body and their own in relation to her and to their own movements. Every moment teaches a lesson of comfort and safety. Every moment is a learning moment.

Blumberg's results, for example, demonstrate that sensory stimulation that is experienced as a "by-product" of spontaneous, uncontrolled "twitching" stimulate activity in specific areas of M1. The neuroscience literature provides numerous examples of how "activity-dependent" development shapes the synaptic connections and the very architecture of the highest cortical regions of the brain. On every level, such movements within a developing nervous system are vital to its growth, differentiation, and adaptive functioning.

We can better understand the value of positioning and swaddling when it provides a supportive surround, so the baby is "held" within its environment and thus receives continuous cutaneous stimulation. Providing opportunities for the baby to move her hands to her face – to self-regulate, to calm herself should also facilitate tactile stimulation to both face and hands that should contribute to establishing or reinforcing the neural maps in the developing brain.

It's truly amazing to know that when we observe a newborn's behavior, we are actually witnessing a process of transformative development, in which the brain's "motor cortex" is working as a purely *sensory* field. M1 is operating by completely different, yet vitally important rules. It is *receiving* and integrating the kinds of impulses that it will soon (by about three months of postnatal age) *produce*, when it essentially reverses its function and transforms from sensory function to motor function!

We are, I believe, entering a new era of comprehension of neurobehavioral developmental care. Systems such as NIDCAP have rested on a foundation of basic description of neural immaturity and susceptibility to change. We now have some important fundamentals, including previously unimaginable findings, that give us deeper insight into developmental processes. Next steps include more precise understanding of how to manage these processes as part of caregiving and supporting families to carry forward their baby's healthy growth and development.

The interested reader is encouraged to read the paper by Blumberg and Adolph[9] portions of which inspired the writing of this column.

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Rhyme & Reflect

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Affection Connection

Skin-to-skin contact
is great – it's a fact.
Instead of you there and here me,
when together, we are we.

Family, father, mother,
you are like no other.
Nothing compares
with our kangaroo cares.

Your scent, words, and warm loving touch
help me oh so very, very much.
When you have worries, fears or feel blue,
I hope my snuggles help you heal, too.

Tell the staff, the town, the whole world!
I grow best with your arms curled
around me all day long.
I feel calm and preemie strong!