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***Touch's Social Significance Could Be Explained by Unique Nerve Fibers***
*by Lydia Denworth*

# A long-overlooked system of nerves that respond to gentle strokes may be crucial to our ability to form connections with one another

My three sons are nearly all teenagers, and some of the details of their earliest years have begun to blur. Which boy was it who said that funny thing about the dog? Who lost a tooth while crossing the street? But I remember the minutes immediately after each child's birth as sharply as if the boys had entered the world this morning. Given my new baby to hold, I hugged him to my chest, caressed his back and kissed the top of his tiny head. And then we stayed there like that for quite a while, mother and child.

The sense of touch had a lot to do with why those moments were so powerful. Touch has long been understood to be important in nurturing relationships -- so much so that babies who were raised in orphanages without it often died. Those first moments with my children, followed by years of cuddles and hugs, no doubt contributed mightily to the deep bonds between us.

The question of why that should be so has traditionally been the province of psychologists, who have proposed a number of explanations such as attachment theory and increases in oxytocin. Yet these suggestions do not adequately elucidate the immediacy and power of touch, and they leave the underlying biology unexamined. Meanwhile neuroscientists had until recently focused only on the discriminative nature of tactile perception -- how touch allows us to tell a baby's skin from his or her blanket and whether that skin feels feverish. They assumed any emotional aspects of touch came later, after the brain had processed the sensation and had a few hundred milliseconds to add the context of feelings.

That view changed a few years ago, when a small but determined group of neuroscientists proposed that something far more fundamental was going on when I held my babies. Their growing body of research has uncovered another dimension of touch that is separate from its discriminative function. This newly recognized system, known as affective or emotional touch, consists of nerve fibers triggered by exactly the kind of loving caress a mother gives her child. It is possible that these neurobiological foundations of attachment might play a far more significant role in human behavior than has been recognized, forging connections and increasing our chance of survival. These fibers may also help our minds construct and integrate a sense of self and other, informing our awareness of our own bodies and ability to relate to people around us.

***"Affective touch is a potential way in to understanding the development of the normal social brain,"*** says Francis Mc-Glone, a neuroscientist at Liverpool John Moores University in England and a leader in the field. ***"It's giving the brain knowledge of me and you, and the emotional quality of gentle, nurturing touch is a very important feeling that underpins a lot of social interaction."***

## A New Kind of Nerve Fiber

*Neurons* in the skin take in information about everything we contact through a variety of nerve fibers and sensory receptors called *mechanoreceptors* that are specialized for touch. Like the rods and cones of the eye, which deliver separate pieces of information to make up the entirety of what we see, different nerve fibers respond best to different kinds of touch [see box on next page]. They play favorites. Some like to be pushed, for instance, and others like to be stretched. One class of fiber, A-beta, does most of the work of discriminating, and these fibers are all over the body, especially in the palm. Because they are sheathed in a fatty insulation called *myelin*, they are able to conduct the nervous system's electrical messages rapidly. Speed is of the essence if you are stepping on a tack after all. *C fibers* are touch fibers of a different kind. They are unmyelinated and carry information at a much more leisurely pace, up to 50 times slower than their neighbors.

The two C fibers that have received the most scientific attention to date are those for pain and itch. (Although some information about painful stimuli travels quickly, the rich details carried in the C fibers take more time, which is why there is sometimes a delay between when you cut yourself and when it starts to hurt.) Now, says McGlone, who began his career studying pain, "there's another kid on the block." Found only in hairy skin such as that of the forearm or back, as opposed to the nonhairy, or glabrous, *skin of the palm and sole of the foot*, the new fiber is known as a *C-tactile (CT) afferent*, a name that indicates that it conveys messages toward the central nervous system. CT afferents are keenly tuned to the gentle velocity and comfortable skin temperature of a caress, an affectionate pat, or any other form of so-called light or innocuous touch. (Sexual responses are something different, although the line between the two is hard to define because sensual touch can, of course, lead to sex.) Technically speaking, anything below five millinewtons of pressure -- about as light as a postcard -- on the skin qualifies as light touch, in contrast to the high pressure of pain, which is why another term for the relevant nerve fiber is the C low-threshold mechanoreceptor.

The discovery of these fibers actually dates back to 1939, when Swedish neurophysiologist Yngve Zotterman discovered a population of C fibers in the skin of a cat that were different from the receptors that convey pain. Zotterman initially speculated they might play a role in the perception of tickling, although later findings would debunk this notion. No one paid much attention to the discovery, however, and it was thought that if such fibers existed in humans, they must be evolutionary leftovers.

The technique of microneurography, a painstakingly precise method of recording electrical activity in individual nerve fibers using very thin electrodes, allowed scientists to study CT afferents in humans. The first comprehensive report of such fibers in a human face was made in 1990, again by Swedish scientists. Another researcher, Ake Vallbo, a neurophysiologist at the University of Gothenburg, and his colleagues soon found a similar nerve fiber in the hairy skin of the forearm. Like other unmyelinated C fibers, this one was slow to react, but it responded to *light touch*, not pain or itch. *"This was completely new,"* says Hakan Olausson, then a Ph.D. student in Vallbo's laboratory and now a neuroscientist at Linkoping University in Sweden who is working with McGlone. The discovery led to the question that has guided work on these fibers ever since: What are they for?

It is obvious why we need a system to alert us to pain. Without it, we would have trouble surviving. Olausson and Vallbo, who is now emeritus, hypothesized that these new fibers did not function in the way we typically think about touch. Perhaps, they said, they are less about sensing and more about *feeling*, and the rewards of pleasant touch were more than just a happy byproduct of a reassuring pat on the back or a sensual caress. In short, the pleasures of gentle touch might encourage human interaction. "The reward system in our brains promotes behavior that is beneficial to survival," McGlone says. "Looking back in evolution, it became apparent that organisms that work together were far more successful. To promote that togetherness, there was a need to promote the value of close physical contact."

Research into grooming behaviors in other animal species supports that hypothesis. Robin Dunbar, an anthropologist and evolutionary psychologist at the University of Oxford, has argued that grooming in primates supports social bonding and reproductive success. And neuroscientist Michael Meaney of McGill University has shown that rat mothers that lick and groom their babies more often raise less stress-prone pups that go on to be better parents themselves.

Although much about touch remains to be explored in both humans and animals, McGlone admits to getting a little giddy when he considers the possibilities and implications of CT afferents in the field: *"I feel affective touch may be the Higgs boson of the social brain."*

**Attuned to Tenderness**

Olausson, McGlone and their colleagues have spent much of the past 20 years piecing together the properties of CT afferents. McGlone, for instance, began by asking whether it was even possible to quantify something called *"pleasant touch."* Beginning in 1999, he and his colleagues reported on a set of psychophysical studies in which robots brushed people's forearms at 0.5, five or 50 centimeters a second. The subjects described five centimeters a second as the most pleasant. In a related 2009 study, neu-rophysiologists Johan Wessberg and Line S. Loken, both then at Gothenburg, used microneurography to determine that the subjects' report of what was most pleasant was reflected in neurobiology. CT afferents responded most vigorously to being brushed at an average velocity of five centimeters a second, a speed that corresponds nicely to the gentle stroking of affectionate touch-reassuring pats on the shoulder, for example, or a back rub. A study led by their Gothenburg colleague Rochelle Ackerley added to the emerging portrait of CT afferents in 2014 by showing that they are tuned to temperature as well, preferring that of the skin to anything colder or hotter.

In 2002 Olausson and his colleagues published one of the earliest and most important findings about CT afferents, based on studies of a patient known as "G.L." who had a rare condition called neuronopathy that had left her without myelinated afferents but with intact unmyelinated nerve fibers. Initially, when brushed on the forearm, which should have stimulated her remaining CT afferents, G.L. said she felt nothing. But in a forced-choice scenario in which G.L. could not see what he was doing, Olausson stroked her forearm periodically with a small brush and asked her to say whether or not she had been touched. She was almost 100 percent accurate. Clearly, G.L. was capable of detecting this gentle touch, but she had so little experience with the nuances of this sensation that she had not been able to identify it at first.

With training, G.L. began to recognize gentle touch and to describe it as pleasant. The same brushing on the skin of the palm, where no CT afferents are present, produced no response. When the team performed the same test on G.L. in a functional MRI machine, they saw that there was no activity in the area of the brain that normally responds to touch, the *somatosensory cortex*. Instead the response came in the *insular cortex*, connected to the *limbic system* and thought to be important for monitoring emotion and a sense of one's own body known as interoception. The latter sense allows people to perceive their internal states, such as hunger and exhaustion, building a necessary inner awareness. A second neuronopathy patient in England confirmed the findings. The activation in the limbic system revealed by the imaging studies was significant evidence in favor of Olausson and Vallbo's original theory that *CT afferents had more to do with feelings than simply sensation.*

In 2011 Olausson and his colleagues reported on a family in northern Sweden with a hereditary disorder that results in normal myelinated nerve fibers but a substantial loss of unmyelinated C fibers -- essentially the opposite of G.L.'s condition. As expected, this group of subjects was capable of sensing touch in terms of discriminating between tactile sensations but did not find a caress at any speed particularly rewarding. (They also had reduced sensitivity to pain and temperature.) "It was almost like a lesion study," Olausson says. "You remove the afferents, and then touch becomes less pleasant."

Most recently, Olausson's lab has turned to looking at affective touch in babies. Touch is the first sense to emerge in utero, and though far from mature, it is the most strongly developed sense at birth. In a study reported at the 2014 Society for Neuroscience meeting in

Washington, D.C., Olausson's Gothenburg colleague Emma Jónsson used *functional near-infrared spectroscopy (fNIRS),* a noninvasive method of brain imaging, to show that newborns can detect the stroking touch that stimulates CT afferents but not a faster brushstroke, indicating that this secondary touch system is indeed already present at birth. The team is extending its investigation to assess touch sensitivities in children six years and older. The researchers believe affective touch could be key to the bond between mother and child. ***"There must be a system telling newborns that you must be close to caregivers, a system to promote being close to the mother primarily,"*** Olausson says.

**Touch Gone Awry**

As research into affective touch gains traction, scientists are investigating the question of what might happen if the affective touch system goes awry. After all, if touch does play some fundamental part in our social connectedness, perhaps people who struggle with forming bonds respond differently to the gentle stroking others find so pleasurable.

Autism researcher Kevin A. Pelphrey, director of the Center for Translational Developmental Neuroscience at Yale University, was inspired by McGlone to consider affective touch in his work. "I thought it was pretty clear that it might play a role [in autism] because this system of touch projects to the limbic system," Pelphrey says. "We've long thought that the limbic system was different in autism, so is this another route by which social information is processed? And is that different in autism?"

In 2013 Pelphrey and his colleagues published findings from a study in which he put *19 healthy subjects into an fMRI machine and brushed their arms at slow and fast speeds*. The researchers saw social areas of the brain, such as the *insular cortex*, *orbitofrontal cor*tex and *superior temporal sulcus*, an area of particular interest in autism, react more to the slower, gentler brushstrokes than to the faster ones. Those same 19 subjects -- none of whom had autism -- also filled out a questionnaire measuring social behaviors. Those with a tendency toward autistic traits showed a moderately muted response to the slow brushing.

Now Pelphrey's group is studying differences between children with and without autism. If the affective touch system turns out to be abnormal in autism, Pelphrey says, it will suggest that autism is happening very early in fetal development. To see if this secondary touch system could serve as a reliable, early biomarlcer for autism, Pelphrey is using fNIRS to monitor the touch response at birth. "We're using it to study newborns and follow them over time to study the system," he observes. If and when autism develops in some of those babies, Pelphrey's team will refer back to its early testing to see if any signs were apparent.

The link between affective touch and interoception opens up another area of research: addiction. Martin Paulus, a psychiatrist at the Laureate Institute for Brain Research in Tulsa, Okla., is investigating whether he could use CT afferents to probe the neuroanatomy of addicted people or those at risk for addiction. His first results, reported in two studies in 2013, showed that individuals with substance abuse problems showed an overreaction to affective touch in the brain, particularly in the insular cortex. This heightened response to touch might indicate an increased need for other forms of strong stimulation, Paulus says, which might in turn explain the appeal of drugs to this group. On the other hand, a group of drug-addicted individuals a few months into sobriety showed the opposite: a reduced or dulled response to the affective touch. "The whole system gets toned down," Paulus says, perhaps as a consequence of drug use. A study of healthy adolescents, published in 2014, also found increased sensitivity to affective touch in that group compared with adults between the ages of 20 and 55, which may motivate teenagers to seek out experiences that involve pleasurable touch.

Like Pelphrey, Paulus wonders if sensitivity to affective touch could provide a biomarker to predict those at risk of addiction and if it could be altered with treatment. "We're at the very beginning," he says, "but [affective touch] gives us a *neu-roanatomical* scaffold that we can then use to better understand when systems go wrong."

**The Subtleties of Sensation**

The combined evidence, though preliminary, suggests that CT afferents have an important role in our emotional health and that this system is crucial to encouraging human interaction. But not everyone is convinced. David Ginty, a neurophys-iologist at Harvard University who is working to delineate the nerve circuits that control all aspects of touch, theorizes that CT afferents are part of an ensemble of fibers (scientists have identified six other fibers in that category) working together like a symphony to convey information about light touch to the brain. In other words, he suspects that CT afferents alone are not as significant as McGlone and Olausson believe they are. In 2012 other neuroscientists, led by Christian Keysers, now at the University of Amsterdam, reported findings suggesting that despite the activity in the insular cortex brought on by affective touch, there are also significant responses in the more traditional brain area for touch, the somatosensory cortex. That could indicate that the affective touch system is not so separate from discriminative touch after all.

Furthermore, it is likely that CT afferent fibers work with other systems in the brain and body that become activated in response to physical contact. The hormone *oxytocin*, for example, is released by *gentle touch* and increases our social interest. It is clear that oxytocin must work in some way with *CT afferents* in contributing to attachment, but we still do not know how. Olausson and his colleague India Morrison, now at Linköping, are embarking on a study designed to try to tease out the *relation between oxytocin and CT afferents more clearly.*

What we think about how we feel also matters. Just because a touch stimulates our CT afferent fibers does not mean it will be enjoyable to everyone in every circumstance. If a stranger caresses your arm on the subway, you are unlikely to interpret the touch as pleasant. One of Olausson's and Wessberg's colleagues, Dan-Mikael Ellingsen, now at Harvard, investigated such effects in a 2014 study. Subjects were told they were going to receive an oxytocin nasal spray that would enhance the pleasantness of touch; in reality, they got a placebo saline spray. Nevertheless, they reported greater pleasantness. But exposing subjects to friendly or angry faces affected their perception of touch. One explanation, Olausson says, may be that competing information from the senses and the brain is reconciled on a case-by-case basis in the same way that we can enjoy the pain of eating spicy foods. If you have CT signaling, he says, there is a good chance you will perceive touch as pleasant, but if there are strong enough conflicting messages (an angry face, a creepy stranger, even a foul odor), the brain can veto the message from the CT afferents and interpret that touch differently.

To really understand the role of affective touch in shaping our brain's social processing, researchers will need to turn to animal models that can provide more precise information. Ginty, for example, studies touch in mice. "It's hard to ask a mouse how something feels," he acknowledges, but the new genetic tools available allow plenty of other tricks you cannot do with humans. Ginty's team is able to visualize and label subtypes of neurons in mice. The researchers can record the activity of those neurons, and perhaps most intriguingly, they can turn off particular sets of neurons to assess the physiological and behavioral responses that result.

Because *touch has been so understudied*, relative to senses such as vision and hearing, and because *work on affective touch is so new*, there is a feeling among those in the field of venturing into thrilling, uncharted territory. **"This is an incredibly exciting time," Ginty says, "because I think over the next five or 10 years, we're really going to crack open the circuits that underlie the responses to different types of [touch) under different conditions."** *As we come to understand this sense better, Ginty believes we will be able to identify and develop new treatment solutions based on touch for conditions as diverse as disorders such as Rett syndrome or autism, neuropathic pain and spinal cord damage. And the interoceptive role of gentle touch could have rehabilitative implications. Ai-katerini Fotopoulou of University College London has found some evidence to suggest that using affective touch in hands-on therapy might help people with brain lesions regain a sense of ownership over certain body parts.*

*For the rest of us, a light touch between intimates, as akin to those early caresses I shared with my babies, remains one of the purest signals of mutual comfort and affection. In a society that so often substitutes virtual communication for personal contact, the findings on affective touch remind us to relish every embrace and hold hugs even a few seconds longer. Those moments may be the bedrock of our richest relationships.*

*Touch is the first sense to emerge in utero, and though far from mature, it is the most strongly developed at birth.*

If touch does play some fundamental part in social connectedness, perhaps people who struggle with forming bonds respond differently to the gentle stroking others find so pleasurable.

**FAST FACTS**

**FULL OF FEELING**

1) A set of nerve fibers called C-tactile (CT) afferents appears to convey information about pleasant touch.

2) Given how attuned these fibers are to human touch, they may play a role in reinforcing social connections.

3) The functioning of these nerves may someday serve as a biomarker for conditions such as autism and addiction.

**The Sensory Body**

*Neuroscientists* have long used a peculiar illustration known as the sensory *homunculus to depict sensitivity to touch.* Each human body part, from toes at the top to tongue at the bottom, is mapped out along the *somatosensory cortex*, a brain region that processes tactile sensation. (In the example above, the location of the somatosensory cortex is also indicated on the brain.) The size of each body part is in proportion to the number of touch receptors present in that area. Hands and lips, for example, provide far more touch sensitivity than the neck or wrists.

In 2014 neuroscientists Susannah Walker and Francis McGlone of Liverpool John Moores University developed an analogous illustration of emotional touch mapped onto the insular cortex, which processes this recently discovered tactile system. Although the rendering (above) is still hypothetical, it reflects the relatively high concentration of receptors for C-tactile afferents in the back, shoulder, scalp and upper arms, as determined experimentally.

**FURTHER READING**

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**From Our Archives**

* Worlds of Feeling. Martin Grunwald; December 2004.

* The World at Our Fingertips. Derek Cabrera and Laura Colosi; September/October 2010.

* A Magic Touch for Stroke Prevention? Stephani Sutherland; July/August 2013.

Pleasurable touch may encourage us to engage in more social interaction with one another, building bonds between individuals.

Varlous types of touch, such as the pain of stepping on a nail (left) or the pleasure of a relaxing massage (right), may engage different nerves in the body to convey their unique messages. Whereas the sharp agony of a cut requires a fast initial response from specialized nerve fibers, the system of nerves involved in gentler sensations are comparatively slow to act.

Because of a rare disorder, a patient (known as "G.L.") was unable to detect many tactile sensations. Yet her nerve fibers related to gentle touch remained intact. Swedish and Canadian researchers observed her brain activity while brushing her arm. In healthy people, several brain areas are engaged by this touching, including the premotor cortex (PMC), which is associated with movement. G.L.'s brain, however, showed less activity overall. A notable exception was her insular cortex (IC). This area is linked to emotions, suggesting *gentle touch relates to feelings.*

Some researchers are investigating whether a negative or subdued response to gentle touch plays a role in disorders characterized by social deficits. For instance, one study has linked autistic traits to a reduced response to a slow brushing stroke on the forearm.

Our system for affective touch most likely works in conjunction with other responses to tactile sensation, such as a rush of the hormone oxytocin, which may heighten the social significance of these interactions.

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