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FEEL ME

What the new science of touch says about ourselves.

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By Adam Gopnik

On a bitter, soul-shivering, damp, biting gray February day in Cleveland—that is to say, on a February day in Cleveland—a handless man is handling a nonexistent ball. Igor Spetic lost his right hand when his forearm was pulped in an industrial accident six years ago and had to be amputated. In an operation four years ago, a team of surgeons implanted a set of small translucent "interfaces" into the neural circuits of his upper arm. This afternoon, in a basement lab at a Veterans Administration hospital, the wires are hooked up directly to a prosthetic hand —plastic, flesh-colored, five-fingered, and articulated—that is affixed to what remains of his arm. The hand has more than a dozen pressure sensors within it, and their signals can be transformed by a computer into electric waves like those natural to the nervous system. The sensors in the prosthetic hand feed information from the world into the wires in Spetic's arm. Since, from the brain's point of view, his hand is still there, it needs only to be recalled to life.

Now it is. With the "stimulation" turned on—the electronic feed coursing from the sensors—Spetic feels nineteen distinct sensations in his artificial hand. Above all, he can feel pressure as he would with a living hand. "We don't appreciate how much of our behavior is governed by our intense sensitivity to pressure," Dustin Tyler, the fresh-faced principal investigator on the Cleveland project, says, observing Spetic closely. "We think of hot and cold, or of textures, silk and cotton. But some of the most important sensing we do with our fingers is to register incredibly minute differences in pressure, of the kinds that are necessary to perform tasks, which we grasp in a microsecond from the feel of the outer shell of the thing. We know instantly, just by touching, whether to gently squeeze the toothpaste or crush the can."

With the new prosthesis, Spetic can sense the surface of a cherry in a way that allows him to stem it effortlessly and precisely, guided by what he feels, rather than by what he sees. Prosthetic hands like Spetic's tend to be super-strong, capable of forty pounds of pressure, so the risk of crushing an egg is real. The stimulation sensors make delicate tasks easy.

Spetic comes into the lab every other week; the rest of the time he is busy pursuing a degree in engineering, which he has taken up while on disability. The researchers try to use their time with him energetically, so there is an excited murmur while the experiments go on—shoptalk conducted mostly in acronyms and initials. It is perfectly possible to hear a sentence beginning "One of the difficulties about being the P.I. on a DARPA-funded study, post I.R.B. . . ." and see gentle nods of agreement. Though Spetic is an industrial worker, he has been in the study long enough to have absorbed the language of the investigators, and he now speaks easily of "the double-blind data" and "following the expanding parameters of the experiment."

simply by willing the nerves—in what is crudely called his stump, what is politely called his residual—he is manipulating a virtual hand in a virtual space, represented on a flat screen in front of him. He moves his hand through the muscles in his arm by using his head, and the hand on the screen moves, too, reaching out and grasping the ball.

"Turn the stim on," he says, almost longingly. An experimenter raises an eyebrow—protocol stipulates that the subject should not know when the stim is turned on—but he does, and immediately Spetic begins to pick the ball up easily. "I can feel it in my thumb and my fingers," he says. Then he corrects himself: "In this space." Tyler whispers to an observer, "He began saying 'the' thumb or 'the' finger. Now he says 'my' thumb, 'my' finger!"

Touch is not a one-way deduction of sensation but a constant two-way interchange between what Tyler calls the "language" of sensation and the raw data of reception. "What we've discovered is that the language of touch is what matters most," he says. "When we first fed the stimulus in, Igor only felt a tingle. The question was, how do we go from tingle to touch? By analogy, pure sound is something we readily do." Tyler stops and makes a kind of inarticulate cry. "I make a noise, but there's no information in it. Break it up in the right way, and it's words. That's what happens when you have epilepsy—it's a kind of constant brain sound. But the healthy body works with patterns of information. And there's a narrow window within which the body interprets. Shouting 'Baaah!' is not *very* different from talking sense."

Tyler's lab is a hive of busy graduate students and assistants, monitoring screens and fiddling with cables. Tyler glides among them encouragingly. "When we started," he says, "we couldn't get past the tingle. We couldn't make the tingle become touch. There's a nerve called the digital nerve, and it's superficial, close to the skin, so we hooked me up to the stimulus, and I started to feel sensation. It took forever, ninety-eight per cent failure and two per cent success. There were so many things to vary! But finally one pattern emerged: a sinusoidal envelope, modulating at one hertz, that fits within the biological range of rhythm and change. Tighten the wave, and tingle becomes touch. It may be coincidence, but that wave, the one that communicates touch, is just around the rhythm of a heartbeat, a sort of essential bodily beat."

The day wears on; Igor Spetic gets a little sad. "I hate to go," he says, pausing in the doorway and looking back. "When I leave this room, I leave my hand behind."

I started thinking about how touch happens when something buzzed in my pocket that wasn't there. Sometimes we think we're going crazy when we're actually in tune with our time and in synch with our fellows. We go to watch a high-fidelity, high-frame-rate movie, think it looks

and discover that it's the high-place phenomenon, and that, far from a death wish, it may be a backward phenomenon of self-recording: we come to the edge, instantly retreat, and then our brain explains our actions to us and retrospectively reorders our memory to believe that we must have actually been thinking of jumping. And we see a blue-and-black dress and think it's white and gold, and everybody else in the country has the same problem.

Or we begin to get the jumps at feeling a cell phone vibrate that isn't there. I'd feel a distinct, small buzzing, would reach down and—nothing. I thought maybe some nerve ending in my thigh had become so habituated to the vibration that it had gone into permanent iPhone spasm. In fact, as the neuroscientist David Linden explained to me, it involves a predictable misread by something called a Pacinian corpuscle.

"The phantom cell phone is such a widespread thing," Linden says. We were speaking in his office at Johns Hopkins University, in Baltimore. "I think something like ninety per cent of college students report it at one time or another. Something else stimulates the Pacinian—one of the sense receptors in your thigh—and the skin says, 'Oh, it must be that damn cell phone again!' It's a nice example of how our entire skin is a sensing, guessing, logic-seeking organ of perception, a blanket with a brain in every micro-inch. So any vibration near the pocket, and the system organizes it in advance, and interprets it as the buzz of your phone."

Linden's original research involves glow-in-the-dark neurons in mouse brains—he manipulates the mouse's DNA, allowing its neural pathways to shine under blue light like psychedelic poster patterns—but he has written at length about the science of touch and has become widely expert in the field. For Linden, it is where the tingle is. Only recently has brain science fully grasped that skin and touch are as rich and paradoxical as any other part of our humanity. Touch is the unsung sense—the one that we depend on most and talk about least. We know the illusions that our eyes or ears can create. But our skin is capable of the same high ordering and the same deceptions. It is as though we lived within a five- or six-foot-tall eye, an immense, enclosing ear, with all an eye or ear's illusions, blind spots, and habitual mistakes. We are so used to living within our skins that we allow them to introduce themselves as neutral envelopes, capable of excitation at the extremities (and at extreme moments), rather than as busy, body-sensing organs. We see our skins as hides hung around our inner life, when, in so many ways, they *are* the inner life, pushed outside.

"More papers have been published on the molecular and cellular basis of touch in the past decade than in the past century," Linden says. "Over the past fifty years, there have been probably a hundred papers about vision for every paper about touch in the scientific literature.

touch-blind isn't compatible with life. There are no national foundations for the hard-of-touch."

David Ginty, a neuroscientist at Harvard Medical School who studies the "low-threshold mechanosensory neurons" that allow our brains to interpret touch, emphasizes the breakthroughs in animal models that have led to what he calls a renaissance in touch science. "For the basic research, it was the conquest of mouse genetics," he says. "Rodents as animal models have come of age, and our ability to bring modern molecular-genetic approaches to age-old questions on somatic sensation is now incredibly powerful." He goes on to explain how mouse genes allow us to explain human touch: "We can turn an itch system off or turn it on. We're interested in the sensory neurons that innervate the skin. And we try to make sense of the complexity: Why are there so many kinds of sensory neurons? What do they do? How are they integrated to give rise to the perception of a touch?"

The world of tactile research is divided into a bewildering variety of names and specialties—haptics, prosthetics, somatosensory studies, haptic feedback prosthetics, and on and on—but they all have in common the relations between our skin and our sense of ourselves. Linden believes that, among all the new discoveries about touch and haptic sensation, the most important are the least generalized. Startlingly specific touch systems, or "labelled lines," as they are called, have been identified. "Each time we study the touch system more deeply, we realize that it is more specialized than we'd known," Linden says. "These systems aren't usefully understood just as different cognitive responses to the same stimuli—they're completely different integrated systems. There are separate labelled lines for so many seemingly intermingled systems." The difference between "affective" touch—a loving caress—and other kinds, like a threatening or a clinical grope, involves two different sensing systems working in close concert. [cartoon id="a19979"]

Still more strikingly "specific" work is being done, down the hall from Linden's office, by another Hopkins neuroscientist, Xinzhong Dong. Dong is the Einstein of itch, the scientist who established that the itch system qualifies as a labelled line, with dedicated neurons of its own. A native of China, he speaks a clipped, intense, and amiable English. "People used to assume that itch was just small pain, the little brother of pain," he says. "But not so. It's a separate system loaded by itself. There's a lot of debate about how itch and pain are coded in the sensory neurons. A few years ago, we discovered a group of cells that function as a specific itch receptor. And that was a breakthrough."

Dong bred mice whose gene for the suspected receptor was turned off. But, to test the itch system, a reliable means of making mice itchy was required. "Many bodybuilders develop severe

tried it in mice and they scratched very robustly. And the ones without the receptors become insensitive. So that showed the receptor we found was the right one. For itch we have very dedicated behavior. It's really cool. We inject a chemical into a face. If it's painful, the animals use a front paw to gently rub it. If you inject an itchy substance, they use a hind leg to scratch. Almost always animals use their hind paw to scratch. So we can tell if they are itchy or painful."

In videos, you see the difference: mice delicately pawing their faces in mild pain; mice scratching fiercely at an itch—two separate systems, turned on and off like porch lights. Even more, the experiments suggest an odd asymmetry between the two systems. You can trade pain for itch, Dong points out: that's why mice and men both scratch. But it won't work the other way around: you can pain your itch, but you can't itch your pain. A signature of itch is that it's specific to the skin. Your bones can ache, but they can't itch. In still one more experiment, Dong made his itch-specific fibres fluorescent. They appeared, as expected, only in the skin.

Why should itch be so catchy? Why should itch be, as it were, pre-installed and so neatly differentiated from pain? Several theories present themselves. The most probable is that it arises from the paramount adaptive need for animals to guard against parasites, which are more likely to produce itch than pain. If we put insect bites on a dimension measured in pain, they would not register sufficiently or at all. There could be survival value in being able, so to speak, to tell a bug up the ass from a pain in the rear.

One strange thing about the unsung sense is that it has no songs. Every other sense has an art to go with it: the eyes have art, the ears have music, even the nose and the tongue have perfume and gastronomy. But we don't train our hands to touch as we train our eyes to look or our ears to listen. Every now and again, someone comes up with a "touch museum" or starts a program for the visually handicapped to experience art through their fingers. But such enterprises often have a hopeful, doomed feeling to them: they seem more willed than wanted.

Is it possible that the absence of tactile art is a mere accident of history? The historian Constance Classen reminds us that in the eighteenth century touching the objects in proto-museums—cabinets of curiosities and amateur collections—was invited and expected and even, in a way, compulsory. "When the underkeeper of the Ashmolean in 1760 tried to prevent a museum visitor from handling artifacts he was accused of incivility," she writes, in "The Book of Touch," an anthology of writings on the tactile. The current reign of the optical museum—where all the objects are shut away, even ones that demand to be touched to be understood at all, like scientific or musical instruments—is, Classen shows, in "The Deepest Sense," a cultural history of touch, a recent one, due to "the association of touch with irrationality and primitivism." The

Of course, there may be more insurance than *episteme* in this change: when ten people a week come to see your Greek bust, letting them caress it is one thing; when ten thousand come, it is something else. And, indeed, one of the ways in which the ten still distinguish themselves from the ten thousand is that they are allowed to touch the objects: seeing and handling art objects out of their frames and cases is one of the perks of becoming an art professional. (Art pros will often, perhaps unconsciously, talk or even brag about handling a famous thing—"I saw 'The Scream' without its frame and held it up!" "The Jasper Johns flashlight was actually in my grasp and I got a sense of its magic!"—to assert their authority.)

In the absence of art, touch turns easily to entertainment. The high-water mark of the touch world can be found at the haptics conferences that fill the calendar of hapticians everywhere, most notably the Institute of Electrical and Electronics Engineers' annual Haptics Symposium, which this spring was held at a hotel in downtown Philadelphia, on a perfect April weekend. Since the upper hall of the hotel is eerily like a high-school gym, one can get the impression of being at a science fair to which only really smart kids can submit projects. It helps the effect that, haptics engineers being professionally unpretentious, they customarily refer to their innovations as "incredibly cool," as in "Did you see the locating device they developed at M.I.T.? It's incredibly cool!" An I.E.E.E. haptics fair is exactly what Ben Franklin would have dreamed of for American science—practical-minded, eccentric, and, as with bifocals, solving problems that one was not entirely aware were problems until an inventor found a solution to them. [cartoon id="a19992"]

The crowd includes the usual engineering types—Midwesterners, Asian-Americans, Asians from Asia—and, in a historically male-dominated discipline, a surprising number of women. There are also numerous special visitors from Apple and Google, extremely anxious about saying too much about what, exactly, they're looking for, the wrong word likely both to spill the beans to the competition and to boost undue speculation about somebody's startup. The air crackles with the distinctive combination of altruism and entrepreneurialism which governs the tech world.

Many and cool are the devices on offer: a "Novel Vibrotactile Feedback Assisted Mid Air Writing device"; a "New Wearable Fingertip Haptic Interface for the Rendering of Virtual Shapes and Surface Features." And here is the Animotus, designed by Adam Spiers, of Yale, and intended "to communicate proximity and heading to navigational targets"; it's a small white two-story cube that sits innocently in your hand, willfully changing shape as—Wi-Fi'd or Bluetoothed to a G.P.S. system—it nudges and pushes you in the right direction down streets

with his tongue. (Eventually, it might be connected to an obstacle-spotter, so that it actually could replace those guide dogs for the blind.) Another new haptic device allows for long-distance Swedish massage; created by a team of Mexican engineers, it allows the masseuse to simply wave her hands over a motion sensor, which reproduces the precise sensitivities of her touch on the back of a patient lying on a pinpoint-tuned motion-sensor pad. Swedish masseuses would no longer have to leave Sweden; they could stay in Stockholm and e-mail massages anywhere in the world.

The attendees like to assure you, and one another, that it is only in the past few years that they have really put the happy in haptics. The haptics devices that most of us are familiar with are the simple ones that make a controller vibrate when the assassin is killed in Assassin's Creed or the defenseman crunches a forward in NHL 16. The new generation of haptics-makers tend to be a little embarrassed by these primitive devices, which they have been known to refer to as "joy buzzers" or even "whoopee cushions," in comparison with the new generation of haptics. A standard trope in an I.E.E.E. demo is to place the old trembly technology beside the new, sleek and persuasive full-range touch illusion.

William Provancher, formerly a professor of mechanical engineering at the University of Utah, now runs a startup called Tactical Haptics, and had the hit demo of the conference. He can create astonishing touch illusions using simple gaming controls. With the HTC Vive—those virtual-reality goggles—he conjures a vast, empty white skin of space, stretching out to every horizon. Life-size zombies come at you from zombie-style holes that expand within the white sheets, like the resurrected dead in Signorelli's painting of the Last Judgment. Armed only with a bow and arrow—though what you are actually clutching is a controller with a trigger, shaped more or less like a gas-pump nozzle—you can feel the tension on your virtual bow as you release the arrow, and then the flutter of the arrow and the *thunk* of the ground trembling when the arrow strikes an onrushing zombie and he falls.

Heather Culbertson, now a postdoc at Stanford, worked at Penn in its famous GRASP lab—the acronym stands for General Robotics, Automation, Sensing, and Perception—and she has returned to Philadelphia to show off her own invention. It is a haptic system that can create the illusion of a hundred distinct textures when you hold it and drag it against a neutral surface. Metal mesh, metal shelving, sandpaper, linoleum, bubble wrap, cardboard, coffee filter, painted brick: holding a pen-shaped utensil in your right hand, you touch the desired texture's name and then drag the utensil across a countertop, say, and in your fingers you feel exactly the sensation that you would feel if the tool were being dragged across the material you specified. You feel

The Queen of Haptics is Katherine J. Kuchenbecker, the brilliant Stanford-trained engineer who oversees the haptics group at the GRASP lab and supervised Culbertson's work. The daughter of a developmental psychologist—and, one is not surprised to learn, a member of the Stanford volleyball team that twice won N.C.A.A. titles—she recognizes the gratifyingly large number of women engineers in haptics. (It was Kuchenbecker who trained Culbertson, then passed her on to her own supervisor, the formidable Allison Okamura, at Stanford.) She is understandably reluctant to say that women study feelings better because they have more of them than men, but then she more or less says it. "We have a long tradition of women as team leaders in haptics," she volunteers—the founder of the GRASP lab is a legendary roboticist named Ruzena Bajcsy—"and I think it's fair to say that women are drawn to areas of engineering with obvious human interface. Places where what you're doing obviously reaches people, touches them, you might say." [cartoon id="a19996"]

She likes the potential of haptic devices to serve both pros and amateurs. Heather Culbertson's tool allows designers to choose fabrics at a distance and someone searching for clothes online to feel the linen of a summer shirt while sitting at her computer. "What Heather and I did was to take a haptic camera—a touch-based camera—and a swatch of material, and record ten seconds of interaction, dragging the tool back and forth, fast and then slow, light and then heavy," she explains. "But the key to creating a compelling illusion that you're touching a real object is that the sensations you feel match all the motions that you make. So we cut that recording up into tiny pieces, fifty milliseconds or a hundred milliseconds of touch, so that we got the minute details right—exactly what you felt on canvas when you moved fast but pushed lightly, and the next time, when you were going slower but pushing harder." The illusion of texture arises when the vibration pattern is played back. The sensing stylus you hold, which resembles a very fat ballpoint pen with a cable attached to its rump, transmits patterned vibrations to your fingers. In a way, it's something like the needle in the groove of an old-fashioned vinyl album, only it plays back into your fingers rather than into your ears. "When you change how hard you are pressing or how fast you are moving, the spectrum of the vibration waveform changes to match the spectral changes we measured during the original data recording," Kuchenbecker says. "It's like recording a certain natural sound, like a waterfall, and then being able to generate a synthetic sound that sounds the same but goes on forever and never repeats, so it's not just a looped recording. The trick is that we constantly change the properties of the waveform to match the exploration conditions, like adjusting how fast the waterfall seems to be flowing. And it creates a fluid, moving, three-dimensional illusion of texture." Choose your texture, drag the tool across nothing, and you feel touch plus time, which is all that texture is.

appendages that no longer exist continue to feel and even to suffer. In sexual touching, as distinct from the affective kind, touch seems driven toward necessity. Both are forms of hyperbolized touch, making more of the stimulation than the stimulation alone would suggest was plausible.

Igor Spetic, in Cleveland, suffered after his amputation from extreme, persistent pain, which he felt permanently emanating from the hand he no longer had. "It was unbearable, twenty-four seven, as though my hand were in a clamp," he says. Since the last thing he vaguely recalls about his accident is his hand clutched in a vise as he reached out toward the mechanical press that crushed it, it seems that his mind had continued to feel that final moment, like a clanging bell that is the last thing remembered, and still heard on his hospital bed, by the victim of a train accident. His hand is so much there from the brain's point of view that the brain may be creating the pain it thinks the hand ought to be feeling, the last tactile sensation it can recall.

This kind of phantom pain in amputated limbs is a widely observed phenomenon, but for a long time it was thought to be a response to trauma of the "cauterized" nerves in the residual limb. One of the things that Dustin Tyler's project in Cleveland has helped confirm is that it is also a cognitive phenomenon, placed much "higher up" in the system. After the sensors in Spetic's arm were stimulated, his pain diminished, and then vanished. Reassured that the hand had moved on, that the trauma had passed and was no longer in need of response, the brain released it from the emergency state of feeling pain. Tyler thinks that, given the extraordinary cost of supplying his prosthetic hand to amputees—the eventual cost of the operation and the equipment, if it ever becomes widely available, would probably reach tens of thousands of dollars—its brightest future may lie exactly in this kind of therapeutic use for patients with extreme neuropathic and phantom pain. The stim can heal.

In a similar way, even normal pain has turned out to be intricately story-driven. The severity of pain, as Ronald Melzack, of McGill University, and his students showed many years ago, varies dramatically according to the context it takes place in: soldiers getting wounds on battlefields which can send them home from the war are numb and happy; women in childbirth—an off-the-charts agony, measured by any objective standard—report it afterward as painful but productive work, and rarely refuse to have another child because of it. It's not that the soldier doesn't feel the wound, or the mother the labor; but they reorganize their experience to suit their situation. It is one reason that, as has often been pointed out, those who suffer even from debilitating neuropathic pain often lead satisfying lives, while those who are born unable to feel pain usually die young. We can retune the warning system; we can't live without one. Pain is, of course, a critical part of the new science of touch: most of the money for projects like Dustin Tyler's comes from a research arm of the Department of Defense, and the Department of

earlier wars would have left them dead.

Most touch acts are surreptitious or subconscious or quietly social, but sexual touching is sought, specific, pointed in desire, and enormous in consequence. It is, in its way, phantom pleasure—an experience so discontinuous with other feelings that one expects it to be not merely a labelled but a licensed line of its own, as though there were a hundred things to hear and one that must be listened to. Yet while we tend, experientially, to separate sexuality from other forms of touching—or at least men do, seeing sex not as a blossom from the world of the tactile but as a thing unto itself—sexual touch seems, in the realm of neurophysiology, curiously unspecified.

"You'd think this would be a real obvious thing, with conferences about it," David Linden says. "But there seems to be nothing special about the sexual skin. We've got this nerve ending we've looked at and we don't know if it's involved in sexual sensation. There are a lot of them in the clitoris and a lot in the glans penis, at the highest density where most men report the strongest sexual sensations. But that's not proof." It has long been established that on the somatosensory cortex—the "map" that exists in the brain, relating specific areas of the cortex to specific places on the skin—the genitalia are represented both in their expected place (around the lower trunk and upper leg) and then again below the leg, around the feet and toes. This may help explain why, as one student of sexual fetishism reports, "in search data there were 93,885 sexual searches for feet and only 5,831 sexual searches for hands." [cartoon id="a20010"]

"And then there are small meaningful oddities," Linden goes on. "There are people who have orgasm syndrome. They're like what we call pain asymbolics—people who lose the emotional content of pain. You hit them with a hammer, and they know they've been hit, but it doesn't trouble them. The same thing is true of pleasure—we think of orgasm as intrinsically pleasurable. But you can have an orgasm that is more convulsive than compelling. All the same things happen on the periphery—rhythmic contractions of the rectum and so on. But it doesn't feel like much more than a sneeze. What are they missing?" A favorite case in the literature is that of a woman who would get a seizure every time she brushed her teeth—the seizures are probably triggered by the repetitive physical activity—and then the seizure would provoke an orgasm. The steady regimen of tooth-brushing orgasms was exhausting, rather than exalting, and led to an unusual morning dilemma: to brush or not to brush.

Among ordinary people, though, the two touch systems that seem most automatic and involuntary, relating to hurting and wanting, turn out to be among the most socially embedded. Pain is not a shared illusion, and sex is not a cultural condition: cut yourself with a carving knife and it will hurt no matter what company you're in; an orgasm felt like an orgasm to Cleopatra as

and pain enter our lives communally, loaded with the local news.

And so if the acceptable frontier of haptic technology is virtual-reality gaming, the unspoken but quietly recognized frontier is romantic. There is already a "hug shirt" that can transmit touch from sender to wearer. It was designed by Ryan Genz and Francesca Rosella, of the London fashion firm Cutecircuit, who decided, more than a decade ago, that touch was the missing link in modern talk: "We can transmit voice, we can transmit images—but we couldn't transmit touch," Ryan Genz says. Originally made as a sort of giant blood-pressure cuff, constricting and releasing the wearer in haptic harmony with another wearer, the shirt proved alarming, and now one hug shirt merely vibrates in long-range synch with another. The first transatlantic hug happened during a conference in 2006, and still longer, fiercer hugs can be imagined. (The newest designs include L.E.D. elements, so that the trace of the embrace lights up.) The hug shirt's love children are almost too obvious to be enumerated. "The only logical advancement in haptics is to full-on virtual sex," the sex-tech journalist Emma McGowan writes. "Full-body haptic suits are no longer a far-fetched sci-fi nerd's dream." Haptics engineers chat about allowing virtual sex with fictional characters or famous celebrities.

At that point, haptics crosses over not just into erotics but into accessories. As the Canadian researcher Meredith Chivers points out, however, there is a demonstrable disconnect between what women, at least, respond to physically and what they self-report as provocative. When it comes to sex, the science of touch confirms that stories, more than sensations, are what stir us. A story-making machine is more likely than a haptic suit to turn us on, as has been the rule of the erotic life of touch since it began.

Every haptic application, once its cool stuff is demonstrated, is followed by a sober explication from its maker on its four potential uses, always offered in descending order of piety: medicine, prostheses, commerce, and gaming. A haptic device might help you operate on a prostate, add touch sensitivity to an artificial hand, allow you to assess the fabric on an online shirt, or make you feel the trigger pressure when you shoot at zombies in a virtual-reality game.

But the real apotheosis of the enterprise will be achieved when artificial haptic intelligence is successfully modelled in robots. As the long-standing dream of the artificial-intelligence community was to make a computer that could defeat a chess master, it is the dream of the robotics community to make, by 2050, a humanoid-robotic team that can defeat the World Cup soccer champions. Kuchenbecker says, smiling, "It's our BHAG"—the Big Hairy Audacious Goal.

robotlike surgical system. The Da Vinci—a grinning panoply of robotic arms and sharp tiny tools, like the torture device in a Bond film—can operate internally and make incisions with a precision that no human surgeon can hope to have. Although temporarily down for repairs, the Da Vinci bears a sign warning visitors to keep clear of it: "Do Not Touch. Testing Is in Progress. Robot Is Active." Though down, it is apparently far from out, and not to be trifled with. Nearby, a second, chubbier robot, designed to have more cushioned arms and less lethal swing-back, keeps it consoling company. Both reside in a room devoted to robots; nearby are several knee-high would-be soccer players on an undersized soccer field. They will, in principle, be scaled up one day, as they are perfected to meet the BHAG. (For the moment, they tend to fall over and lose their heads when trying to recover the ball and kick it accurately in one move.)

Kuchenbecker's goal is to provide robots with more than mere mechanical expertise. She wants them to have "haptic responsiveness," so that the surgeon operating the robot can feel in her own hands the bounce or flab of an internal muscle, or palpate a liver from long distance. Ultimately, that intelligence could be infused in the robot itself, so that it would need no human to control it. [cartoon id="shaw-2010-08-09"]

"Haptic intelligence is vital to human intelligence," she concludes. "It's not just dexterity. It's finding your way in the world: it's embodiment, emotion, attack. Haptic intelligence is human intelligence. We're just so smart with it that we don't know it yet. It's actually much harder to make a chess piece move correctly—to pick up the piece and move it across the board and put it down properly—than it is to make the right chess move." She adds, slyly, "When I took A.I. as a student, I was so dismayed to find that most A.I. is just stupid brute force, just running through the possibilities a machine can look at quickly. Computer chess *looks* intelligent, but it's under-the-hood stupid. Reaching and elegantly picking up the right chess piece fluidly and having it land in the right place in an uncontrolled environment—*that's* hard. Haptic intelligence is an almost irreproducible miracle! Because people are so good at that, they don't appreciate it. Machines are good at finding the next move, but moving in the world still baffles them."

The study of haptic intelligence leads to even deeper questions about the somatic self. Our skin is us because it draws a line around our existence: we experience the world as ourself. We can separate ourself from our eyes and ears, recognize the information they give us *as* information, but our tactile and proprioceptive halos supply us with the sense that we are constant selves.

There are rare conditions in which you come to believe that while, say, the right half of your body is you being yourself, the left half of your body is someone else's—some uncomfortably

alien abductions. The possibility of such illusions suggests that their opposite—our agreed-on coherent sense of a continuous self—may be a convenient fiction, an organized cognitive heuristic that we impose on experience to let us go on having it.

When somatic illusions strike, in other words, they strike our very sense of who we are. It is possible, by tapping at sequential spots on the skin, to create the illusion of intermediate taps between them, as though a rabbit were hopping down our arm. The so-called "cutaneous rabbit," whose paws we feel strongly, can even be made to hop out of the body and leap onto a stick held by a subject. (The stick shakes, or so the subject feels, as though the rabbit had jumped on it.) The rabbit is just us, leaping out of our own skin.

In another way, it is increasingly possible to imagine oneself as being discontinuous with one's skin. Igor Spetic feels something like this when he leaves his hand behind. "Think about it," Dustin Tyler says. "There's no real constraint on how far in space the connection could go. You could be sitting here in Cleveland and performing surgery in Tahiti, and actually feel the flesh and organs of your patient. Actually feel them. For that matter, you could text-message a handshake to a friend." Even a visitor, playing with Spetic's virtual hand, without the added bonus of the "stim" that enables him to feel the surface shapes of nonexistent objects, can find the experience of solving problems so intense that he feels that his hand, too, is in there, on a screen, inside a box. You are here; your hand is six feet away. The philosopher Daniel Dennett, playing with this idea, came up with a thought experiment in which one's brain sits in a vat in Texas while artificial, remote-controlled hands and eyes and limbs engage at its direction from Oklahoma. The essay he wrote about this thought experiment was titled, simply, "Where Am I?" For the first time, this fantasy is becoming readily imaginable in the real world: in a sense, Spetic's hand is left in the lab on the weekend. A bit of him is there.

It can sometimes seem as if the world of thinking about touch were divided into that of philosophers and students of culture who study the "phenomenology" of sensing, and that of the scientists and engineers who study its mechanics, with an abyss of understanding between them. In the introduction to "The Book of Touch," Constance Classen explains that the anthology "does not offer any scientific information about touch," because "attempts to explain tactile culture through scientific models tell more about the culture of science than about the scientific basis of culture." The humanists are certain that what the scientists are doing is really cultural studies that don't yet know themselves.

One of the few "multilinguals" in the field—someone equally at home with neuroscience and with phenomenology, with the language of data and with the talk of daily human experience—is

little girl. I dropped him a line one Sunday morning, and discovered that, serendipitously, he was in New York that day. He suggested that I meet him that very afternoon, in Washington Square Park, where he was "going to spend some time watching people be embodied."

I found Keltner, calm and inquisitive, observing the world from a park bench. He looks like a Pixar version of the emotion of Benevolence: graying blond hair, worn long and parted in the middle, a serene smile always on his lips, and creased eyes suggesting perpetual, hope-filled curiosity mixed with wisdom. He explained that he likes to come out and watch emotions becoming embodied, by which he means seeing all the ways in which people take on the poses of their feelings, with the additional twist that he thinks, in effect, that the poses come first. In his view, touch is the primary moral experience: it is morality as we experience it in the first instance in the actual world. The thoughts come afterward to administer the thing. "Touch is the first system to come online, and the foundations of human relationships are all touch," he says. "Skin to skin, parent to child, touch is the social language of our social life. It lays a basis for embodiment in feeling."

Keltner has the power, shared by true students of a science, to make one see with his eyes: looking out across the panoply of human interaction in the sunlit square, one sees at once how much depends on skin and near-skin encounters: dating couples lean forward, hair brushes and fingertips touch; children bump as they play, not too hard and then hard enough to be warning and instructing; chess players off in their corner imply tentativeness, certainty, triumph, and mid-game anxiety by the sureness or the uncertainty with which they grasp and move their pieces. [cartoon id="noth-2010-12-13"]

"The foundation of human relationships is all touch," Keltner goes on. "There are four years of touch exchanged between mother and baby. Among primates, the sense of reciprocal altruism emerges from food sharing, and they are always systemically touching each other as they share food. Reciprocity is tactile. Aggression is tactile. Sex is tactile. It's the root moral precept of our sense of common humanity. In the social realm, our social awareness is profoundly tactile." Keltner was one of the co-authors of a much talked of study that encoded twelve distinct kinds of "celebratory touches" among pro basketball players, including "fist bumps, high-fives, chest bumps, leaping shoulder bumps, chest punches, head slaps, head grabs, low fives, high tens, full hugs, half hugs, and team huddles." They discovered that teams whose players touched one another a lot did better than those whose players didn't. Touch lowers stress, builds morale, and produces triumphs—a chest bump instructs us in coöperation, a half-hug in compassion.

homunculus in our heads. Our bodies are membranes in the world, with sensation and meaning passing seamlessly through them. Our experience of our bodies—the things they feel, the moves they make, and the textures and the people they touch—is our primary experience of our minds. "The brain is just simply part of our bodies" is how the philosopher Alva Noë often puts it. The truer cartoon, in a sense, would be "Outside In," with the emotions produced by people bumping against one another. A key to being embodied in this way is tactile experience—what we touch, whom we touch, how many we touch, and why we find them touching. Grasping, hugging, striking, playing, caressing, reaching, scratching backs, and rubbing rears: these are not primitive forms of communication. They are the fabric of being conscious. The work of the world is done by handling it. We live by feel.

Later, in a café near the square, Keltner has a cappuccino and, sitting at the counter, watches the variety of human touch as it reveals itself in that unending theatre: fingers flying on the keyboard, hands darting out to make a point, heads turning to underline a joke, bodies slouching and primping and jostling and soliciting attention. An intensity of feeling combines, in our tactile lives, with a plurality of kinds.

Perhaps the reason that touch has no art form is that its supremacy makes it hard to escape. We can shut our eyes and cover our ears, but it's our hands that do it when we do. We can't shut off our skins. It is the obscurity of the other senses that makes us enliven them with art: touch is too important to be elaborated or distilled. It just is. What we see we long for; what we hear we interpret; what we touch we are. The art we aspire to is a remote sensation, always out of reach. Life is the itch we are still trying to scratch. ♦

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