



Touch: The Science of the Hand, Heart, and Mind

By David J. Linden

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Editorial Review

Review

“[Linden is] an able guide to the world of touch, with a true gift for simplifying the complex. (The illustrations and diagrams throughout the book help, too.) The book is packed with cocktail-party trivia—scientists believe that touch is the first sense to develop in utero; some people with schizophrenia can tickle themselves—and satisfying explanations of everyday tactile experiences.”

—**Emily Anthes, *The Washington Post***

“With a novelist’s flair for anecdote, Linden unpacks the science behind touch by revealing how the sense informs and motivates us in everyday situations.”

—**Bob Grant, *The Scientist***

“A book for the non-expert on the neuroscience of touch is very welcome, and I recommend this one enthusiastically. It’s full of facts and explanations, many of which are totally cool and, some, even astonishing But what endears me to the book is not its clarity and its informativeness. What I love is its openness, and occasional insightfulness, about all the things we don’t know.”

—**Alva Noë, NPR.org’s *13.7: Cosmos & Culture* blog**

“*Touch: The Science of Hand, Heart and Mind*, is a treasure trove for anyone wanting to decode the frisson of a lover’s caress. After all, the skin, says Linden, is a social organ.”

—**Cat Auer, *Playboy***

“The best science writers infect you with their fascination for the subject—that’s exactly what Linden achieves here.”

—**Christian Jarrett, *BBC Focus***

“This book is about the sense of touch, it’s by a professor of neuroscience at the Johns Hopkins School of Medicine, and it’s excellent. It will tell you why footballers hug each other when a goal is scored, why they are like vampire bats in this respect, and why some people like being the recipients of anal sex while others don’t. David Linden tells us all of this with exactly the right degree of scientific dryness.”

—**William Leith, *The Spectator* (UK)**

“Linden explores touch in depth, from itches to orgasms . . . and it makes for compelling reading.”

—**Orlando Bird, *Financial Times***

“Being out of touch, the American neuroscientist David J Linden argues in his absorbing book, is not just something that happens to cabinet ministers The human brain contains 500 billion nerve cells and does not give up its secrets lightly. But following Linden’s thread is profoundly worth it.”

—**Oliver Moody, *The Times* (London)**

“An engrossing book This book has changed my own life in a small but significant way. My family joke that I’m the woman who put the ‘sal’ into ‘salad’ as I’ve spent my life grazing on uncooked veg. I now gulp down hot soup and feel the better for it. Thank you, David Linden.”

—**Salley Vickers, *The Guardian***

“David J. Linden’s *Touch* is a charming read that explains the science of touch in easily understandable terms. Anyone who is interested in human interactions and emotional connections will find this book interesting. Just as important, men and women who deal with intimacy disorders – including love and sex addiction—are likely to find this book enlightening from a disease and recovery standpoint.”

—**Scott Brassart, *Addiction.com***

“The Johns Hopkins neuroscientist leads us on a delightful tour of the science of touch, sharing discoveries that shed new light on this highly under-appreciated sense.”

—**Jill Suttie, *Greater Good***

“If you’re interested in the mechanics of your mind or you want to know why you itch and what you have in common with koalas, read this and you won’t be disappointed. *Touch: The Science of Hand, Heart, and Mind* is a book to get your fingers on.”

— **Terri Schlichenmeyer, *Rockdale Citizen***

“The book is highly readable and laced with stories that are fascinating, funny and surprising!”

—**Viviane Crystal, *The Best Reviews***

“Though the author includes a host of entertaining anecdotes, his narrative is consistently backed by solid science. So surpassing does Linden make touch seem that even turning the pages of his book becomes a pleasurable experience.”

—**Kirkus Reviews**

“Why does sexual touch feel good? What is the difference between being touched on one’s palm or shoulder? Of all the senses, touch is by far the most underrated, according to Johns Hopkins neuroscience professor Linden (*The Compass of Pleasure*, 2011)This in-depth, awareness-raising discussion of the effects of touch from head to toe and back again sheds light on a fascinating yet overlooked topic.”

—**Donna Chavez, *Booklist***

“The sensation of touch, so ubiquitous in how we interact with our world, gets a sensualist pop-biology treatment from Linden (*The Compass of Pleasure*), a professor of neuroscience at the Johns Hopkins University School of Medicine. . . . Though it’s not exactly a neurobiology primer, Linden sandwiches a surprising amount of anatomical information between the stories of bad hand jobs and children who die young because they can’t feel pain.”

—**Publishers Weekly**

From the Hardcover edition.

About the Author

David J. Linden is a professor of neuroscience at the Johns Hopkins University School of Medicine. The author of *The Accidental Mind* (2007) and *The Compass of Pleasure* (2011), he served for many years as the chief editor of *The Journal of Neurophysiology*. He lives in Baltimore, Maryland with his two children.

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PROLOGUE

Malibu, Summer 1975

We're eight teenage campers huddled around a fire ring, late at night. Piled up like puppies, spilling over rocks and stumps and the dusty bare dirt of the Santa Monica mountains, we smell of black sage and acorns and unwashed T-shirts. With no adults in sight and the soft cover of darkness, we give voice to our innermost pubescent thoughts.

"Your turn, Sam."

"Okay . . . this is for Caroline. Would you rather give an open-mouth kiss to the camp director or eat a live cockroach?"

Our voices rise in a disgusted, delighted Greek chorus, "Eeeeeeeeeew!"

"You're so gross, Sam. I'm not answering that one."

"But you have to. Those are the rules."

"No way, you pervert."

"You're so prickly. I didn't mean to hurt your feelings."

"Yeah, right."

"Okay, here's a clean one. Would you rather die of cold in Antarctica or heat in the Sahara Desert?"

"I'm not allowed to bring a parka to Antarctica?"

"No, you're naked."

"Then I choose the desert. I want to go out with a good tan."

Good-natured howling erupts. Caroline raises her arm and shimmies, vamping it up.

Sam smiles. "You're so vain. And . . . I've gotta go." Everyone knows that this is bogus. It's obvious that he's crazy about Caroline.

"No, you don't, you slippery sonofabitch. Now it's *my* turn. You must give up all of your senses except one. Which do you pick to save?"

"Oh, man. That's rough. I'd keep sight. Then, at least I could get around. Uh, no, hearing—I need my music. Shit. I dunno. That would just suck."

"Yeah, it would."

"I'm touched by your concern."

"Bite me."

Later, lying in my sleeping bag and mulling over this flirtatious banter, I was puzzled. Flush with hormones, we all hungered for interpersonal touch, for kisses and caresses and more. I was typical of this group, so

consumed with the idea of holding and kissing a lovely dark-haired girl named Lorelei that I could barely speak. Touch was central to our obsessions and fantasies, yet none of us ever chose to preserve it when, in the nights that followed, Caroline's question about losing one of our senses returned in the "Would you rather . . . ?" game. Did we simply not think the ramifications through? It's certainly true that a bunch of horny sleep-deprived amped-up teenagers sitting around a campfire is not the ideal forum for contemplation. Or was it that we could easily imagine what it would be like to experience the loss of sight or hearing (we had all shut our eyes or plugged our ears), or even of taste or smell, yet none of us had ever actually been able to re-create the sensation of the loss of touch. Perhaps touch was woven so deeply into our sense of self that we could not truly imagine life without it. Years later when I read *Lolita*, I discovered that Vladimir Nabokov had, as usual, raised this very issue many years before: "It is strange that the tactile sense, which is so infinitely less precious to men than sight, becomes at critical moments our main, if not only, handle to reality."

For Nabokov's Humbert Humbert, touch was so infinitely precious an experience that even the merest tactile contact with his beloved Lolita aroused overwhelming passions. For all of us, the experience of touch is intrinsically emotional, and this is reflected in common expressions in English. Read the dialogue that opens this chapter and notice that phrases like "I'm *touched* by your concern" or "I didn't mean to hurt your *feelings*" and texture metaphors like "you're so *prickly*" or "that's *rough*" or "you *slippery* sonofabitch" didn't stand out at all. We are completely accustomed to describing a wide range of human emotions, actions, and personalities in terms of our skin senses:

"I was touched by her thoughtfulness."

"It's a sticky situation."

"That's enough of that coarse language."

"That is one hairy problem."

"He rubs me the wrong way."

In everyday speech, the tactile is so entangled with the emotional that when we encounter someone who is emotionally clumsy, we call him *tactless*: Literally, he lacks touch.

This may seem like a silly question, but it's not: Why are emotions called *feelings* and not *sightings* or *smellings*? Do touch metaphors really tell us something about the skin senses and their relationship to human cognition, or are they merely a common usage of present-day English? In fact, the constructions "I'm touched" to mean "I'm emotionally affected" and "my feelings" to mean "my tender emotions" have been in use in the language since at least the late thirteenth century. And such expressions are not unique to English, or even the Indo-European language group, as they are found in tongues as diverse as Basque and Chinese.

People who are blind or deaf from birth will for the most part develop normal bodies and brains (apart from the visual or auditory areas) and can live rich and fruitful lives. But deprive a newborn of social touch, as occurred in grossly understaffed Romanian orphanages in the 1980s and 1990s, and a disaster unfolds: Growth is slowed, compulsive rocking and other self-soothing behaviors emerge, and, if not rectified, emergent disorders of mood, cognition, and self-control can persist through adulthood. Fortunately, even a relatively minor intervention—an hour per day of touch and limb manipulation from a caregiver—can reverse this terrible course if applied early in life. Touch is not optional for human development. We have the longest childhoods of any animal—there is no other creature whose five-year-old offspring cannot live independently. If our long childhoods are not filled with touch, particularly loving, interpersonal touch, the consequences are dramatic.

The critical role of touch in early development has not always been appreciated. Child-rearing advice of the 1920s from the psychologist John B. Watson (the founder of the psychological movement called behaviorism) cautioned parents about spoiling their children with physical affection: “Let your behavior always be objective and kindly firm. Never hug and kiss them. Never let them sit on your lap. If you must, kiss them once on the forehead when they say goodnight. Shake hands with them in the morning. Give them a pat on the head if they have made an extraordinarily good job of a difficult task.”¹

While most parents today do not restrict contact with their children to an occasional pat on the head, it’s a different story outside the family. In our zeal to protect kids from sexual predators, we have promoted no-touch policies for teachers, coaches, and other supervisory adults that, while well meaning, have the inadvertent effect of adding to the touch deprivation of our children. As these kids have grown up in a touch-phobic environment and propagated these fears to their own children, our society as a whole has become further impoverished.

You may ask, “Okay, I understand that kids are sensitive, but once we’ve become adults, why does it matter if we’re touch-deprived? This touchy-feely stuff is for hippies and time wasters. Just squirt out another glob of hand sanitizer (with that deeply satisfying *blorp* sound) and get back to work.” The answer is that interpersonal touch is a crucial form of social glue. It can bind sexual partners into lasting couples. It reinforces bonds between parents and their children and between siblings. It connects people in the community and in the workplace, fostering emotions of gratitude, sympathy, and trust. People who are gently touched by a server in a restaurant tend to leave larger tips. Doctors who touch their patients are rated as more caring, and their patients have reduced stress-hormone levels and better medical outcomes. Even people with clipboards at the mall are more likely to get you to sign their petitions or take their surveys if they touch your arm lightly.

The main point of this book is not merely to argue that touch is good or even that touch is important. Rather, it’s to explain that the particular organization of our body’s touch circuits, from skin to nerves to brain, is a weird, complex, and often counterintuitive system, and the specifics of its organization powerfully influence our lives. From consumer choice to sexual intercourse, from tool use to chronic pain to the process of healing, the genes, cells, and neural circuits involved in the sense of touch have been crucial to creating our unique human experience.

The transcendence of touch resides in the details, and, of course, these have been sculpted over the course of millions of years of evolution. They’re in the dual-function receptors in our skin that make mint feel cool or chili peppers hot. They’re in the dedicated nerve fibers in our skin that predispose us to like a soft caress (but only if it moves at the proper speed across the skin). And they’re in the brain’s specialized centers for emotional touch, without which an orgasm would seem more like a sneeze—convulsive, but not compelling. And lest we begin to think that everything’s hardwired and predetermined, these same emotional touch centers are neural crossroads where sensation and expectation collide, allowing for powerful effects of life history, culture, and context. Activity in these brain regions determines whether a given touch will feel emotionally positive or negative, depending upon the context in which it occurs. Imagine a caress from your romantic partner during a sweet, quiet connected time versus one that is administered right after he or she has said something deeply offensive. Similarly, these regions are where the neural signals engaged by the placebo effect, hypnotic suggestion, or even mere anticipation can act to dull or enhance pain. There is, in fact, no pure touch sensation, for by the time we have perceived a touch, it has been blended with other sensory input, plans for action, expectations, and a healthy dose of emotion. The good news is that these processes are no longer entirely mysterious. Recent years have seen an explosion in our scientific understanding of touch, revealing new ideas that help explain our sense of self and our experience of the world. So let’s dive in. The water’s not so cold once you get used to it. It will feel great.

CHAPTER ONE

THE SKIN IS A SOCIAL ORGAN

Warsaw, 1915

Solomon Asch was brimming with excitement. At the age of seven he had been allowed to stay up past his usual bedtime for his first Passover Seder. In the warm glow of the candles, he watched his grandmother pour an extra glass of wine that didn't match a place setting.

"Who's that glass for?" Solomon asked.

"It's for the prophet Elijah," explained an uncle.

"Will he really come inside and have some wine?"

"Certainly," the uncle replied. "You just watch when the time comes, and we open the door to let him in."

The extended family gathered around the table and read from the Haggadah, which tells the story of the Jews' liberation from slavery in Egypt in the time of Moses. Following the teachings of the Talmud, prayers were intoned, wine was drunk, parsley was dipped in salt water, and a festive meal was consumed while reclining in the manner of free people of the ancient world. After the meal, as tradition dictates, the front door was opened to admit the prophet. A moment later, Solomon, primed with expectation and inspired by the Passover ritual, saw the meniscus in the wineglass drop just a bit, as if Elijah had taken a single sip before slipping out the door to visit other Jewish families.

Figure 1.1 Solomon Asch, a leader in the fields of social and Gestalt psychology. This photo was taken in the 1950s, when Asch was a professor in the department of psychology at Swarthmore College. He died in 1996, at the age of eighty-eight. Used with permission of the Friends Historical Library at Swarthmore College.

Solomon Asch emigrated with his family to New York City at the age of thirteen and soon learned English by reading the novels of Charles Dickens. As he grew older, he became fascinated with psychology, particularly social psychology, and earned his doctorate in that field in 1932 at Columbia University (figure 1.1). Years later he credited his interest in the field to his experience on that boyhood Passover night. How could the collective faith of the Seder celebrants lead him to believe in something like the prophet's sip of wine, which was demonstrably impossible? This was not just an academic question. With the rise of Hitler and Nazism in Europe, Asch became particularly concerned with two related sociopolitical questions that would hold his attention throughout his career: How can the social world shape our beliefs in the face of clear contradictory evidence? And how do we come to form rapid decisions about another's character? He wrote, "We look at a person and immediately a certain impression of his character forms in us. A glance, a few spoken words are sufficient to tell us a story about a highly complex matter. We know that such impressions form with remarkable rapidity and with great ease. Subsequent observation may enrich or upset our first view, but we can no more prevent its rapid growth than we can avoid perceiving a given visual object or hearing a melody."¹

Asch wanted to know if there were underlying principles that guided this quick formation of character impressions. After all, everyone we encounter presents us with an array of diverse characteristics. One person is courageous, intelligent, with a ready sense of humor, and swift in his movements, but he is also serious, energetic, patient, and polite. Another is slow, deliberate, and serious, but has a fast temper when

provoked. How do such perceived characteristics come together to form an overall impression of an individual and enable us to extrapolate and predict his behavior in various circumstances? Does each separate characteristic join together in a whole to form our perception, or does one particular characteristic, or a small cluster of them, dominate our overall impression? Crucially, how do these processes play out for public figures like Hitler, Churchill, or Roosevelt, with whom few people interacted directly?

In 1943, midway through World War II, Asch devised an experiment to begin to address these questions. He recruited subjects—mostly young women during these wartime years—from undergraduate psychology classes at various universities in New York City, such as Brooklyn College and Hunter College. “I shall read to you a number of characteristics that belong to a particular person,” he told one assembled group. “Please listen to them carefully and try to form an impression of the kind of person described. You will later be asked to write a brief characterization of the person in just a few sentences. I will read the list slowly and will repeat it once: Intelligent . . . skillful . . . industrious . . . cold . . . determined . . . practical . . . cautious.” A second group heard the same list with a single substitution: “cold” was changed to “warm.” A sample response from someone forming an impression from the series including “cold” read: “A very ambitious and talented person who would not let anyone or anything stand in the way of achieving his goal. Wants his own way. He is determined not to give in, no matter what happens.” A member of the warm group, in contrast, replied: “A person who believes certain things to be right, wants others to see his point, would be sincere in an argument and would like to see his point won.” The subjects were also asked to elaborate on their impression by picking one of a pair of opposite descriptive terms (like generous/ungenerous, sociable/unsociable, humane/ruthless, strong/weak, reliable/unreliable, or dishonest/honest) to describe the “cold” and “warm” individuals. When the responses were analyzed and appropriate statistical tests applied, it became clear that the warm/cold distinction was very significant. The person described as warm was more often rated as generous, sociable, and humane, while the cold person was viewed as ungenerous, unsociable, and ruthless. The warm person was not, however, rated as more reliable, strong, or honest, indicating that the “warm” descriptor did not confer an across-the-board positive shift in impression. Rather, perceiving someone as warm indicates a specific constellation of traits: helpfulness, friendliness, and, most important, trustworthiness. Simply put, warm people are not identified as threats.²

Subsequent experiments and observations outside the laboratory by Asch and many others have shown that the warm/cold dimension is the strongest component of both the first impressions of individuals (the second strongest being competent/incompetent) as well as of group stereotypes when evaluated across many countries and cultures.³ Why do we respond so naturally to the linguistic metaphor of the warm individual? It is likely that this metaphor has deep biological roots. We often use terms familiar from our sensory experiences to organize abstract psychological concepts. In both our individual lives and our human evolutionary history, the physical sensation of warmth has been associated with security, trust, and an absence of threat, mostly through the experience of a mother’s touch.⁴

Asch’s model of impression formation suggests an obvious question: Does physical warmth relate to metaphorical warmth? Specifically, in adults, does the mere tactile experience of warmth on the skin activate feelings of interpersonal warmth that can transfer to our evaluation of an unknown person? To investigate this question, Lawrence Williams and John Bargh, of the University of Colorado and Yale, respectively, devised a clever experiment. Subjects were met in the lobby of the psychology building by an employee of the experimenters. This employee—who, crucially, was blind to the intent of the study—was carrying an awkward load: a cup of coffee, a clipboard, and two textbooks. During the elevator ride up to the lab on the fourth floor, she casually asked each subject to hold her coffee cup while she recorded the subject’s information on a form attached to the clipboard. She then took the coffee cup back and delivered the subject to the experimenters. In some cases the cup contained hot coffee, and in others, iced coffee. When the subjects arrived in the lab they were immediately given a personality assessment questionnaire like that used in Asch’s original 1943 study but without the warm/cold terms (e.g., person A was described as intelligent,

skillful, industrious, determined, practical, and cautious). They were then asked to rate this fictional person on ten traits using the previously described method of opposites (humane/ruthless, dishonest/honest, and so on). They found that subjects who had held the hot coffee cup perceived the target person as being significantly warmer (humane, trustworthy, friendly) than those who had held the cup of iced coffee. Remarkably, the brief experience of physical warmth on the skin of the hands did indeed promote interpersonal warmth.⁵

Is the influence of incidental tactile experience on our evaluation of an unknown person unique to warmth, for which we have an unusually strong positive emotional association, or does it apply more broadly to touch sensations in general? Could other skin sense experiences subconsciously influence our impressions about unrelated people and situations? Guided by rich tactile metaphors in the English language, like “weighty matters,” “the gravity of the situation,” “smooth negotiation,” and “hard bargainer,” John Bargh, now joined by Joshua Ackerman and Christopher Nocera, set out to test this broader hypothesis.⁶ First, they had passersby evaluate a single job candidate by reviewing a résumé affixed to either a light or a heavy clipboard (340 grams versus 2,041 grams, the latter being the weight of a typical medium-sized laptop computer). Subjects given the heavy clipboard rated the candidate as significantly better overall and as showing more interest in the position. The tactile experience of the weighty clipboard subconsciously caused the job applicant to be perceived as having significantly better performance and more serious intent. Importantly, the weighty clipboard did not influence subconscious impressions generally: For example, the candidate was not rated as more or less likely to get along with coworkers. Rather, the heavy clipboard specifically conferred gravitas.⁷

Bargh’s group moved on to explore texture, influenced by metaphors like “I had a rough day.” In this study, passersby were first asked to complete a simple jigsaw puzzle, one group being given a puzzle in which the pieces were covered in sandpaper, and the other group an identical puzzle with smooth pieces. All subjects were then asked to read a passage describing an interaction in which the social valence of the situation was deliberately ambiguous. When subjects were asked to rate the quality of the interaction in the passage, the rough-texture subjects scored it as significantly more adversarial (versus friendly), more competitive (versus cooperative), and more like an argument than a discussion. The physical experience of a rough texture changed evaluations of a social interaction to make it seem more metaphorically “rough.”⁸

Finally, a similar study was conducted using hard versus soft as the tactile manipulation. Here the psychologists disguised the touch experience by embedding it in the ongoing patter of a magic act. Passersby were asked to watch a magic trick and guess its secret. As a part of the show, subjects were asked to examine an object to be used in the trick, ostensibly to confirm that it had not been tampered with. Some subjects fondled a soft swatch of blanket; others, a hard block of wood. The magic act was then postponed while the subjects were asked to read the same deliberately ambiguous social interaction passage used in the rough/smooth study, with the difference being that they were told that the interaction was between an employee and a boss. When asked to evaluate the employee, subjects primed with the wood block were significantly more likely to rate him/her as rigid and strict, consistent with hardness as a metaphor for an unyielding, unemotional personality. (And, no, sadly, the subjects never actually got to see the magic trick.)

The fact that even incidental touch experience can influence our impressions of people and our social interactions can be more than a little disconcerting. How would that beautiful, intelligent woman I was chatting up at the Caffe Med in Berkeley in 1983 have reacted if she had had her hand wrapped around a hot cup of coffee instead of that cold Italian soda? And what about that weird department chairman who compulsively squeezed a hollow rubber ball while he interviewed me for an academic job? If he had been toying with a letter opener, would he have tended to regard me as sharper, or merely hard and unyielding?

While the Bargh incidental touch studies were well designed and their findings are useful and interesting,

they do have serious limitations. Most important, they do not capture impressions as they occur in real-world situations. Survey-based experiments require that subconsciously formed impressions be made conscious and explicit, and the responses of the subjects must conform to the experimenter's predetermined scales of measurement. This is an unnatural situation. In our daily lives we are continually forming ideas about people and situations but are not simultaneously making mental checklists assessing them on the basis of "humane versus ruthless" or "discussion versus argument." That's why it's important to investigate the social roles of touch in everyday contexts.

Figure 1.2 Interpersonal touch predicts increased performance in the NBA. Top: Bar graph shows total celebratory touch duration scored in a single early season game for winning and losing teams in the five games that followed during the 2008–9 NBA season. From M. W. Kraus, C. Huang, and D. Keltner, "Tactile communication, cooperation and performance: an ethological study of the NBA," *Emotion* 10 (2010): 745–49. Published by the American Psychological Association; reprinted with permission. Bottom: Basketball players engaging in an airborne chest bump.

With its complex social milieu, clear measures of team and individual performance, and plenty of butt slapping, high fives, and chest bumps, there is no better tactile/social living laboratory than the National Basketball Association (NBA). This was the insight of a research group at UC Berkeley composed of Michael Kraus, Cassy Huang, and Dacher Keltner. They reasoned that since interpersonal touch can promote trust and cooperation, two important factors for a successful basketball team, increased touch between teammates early in the season should predict more cooperative behavior and better performance as the season unfolds.

To measure this, Kraus and coworkers first watched videotapes of games featuring all thirty NBA teams (294 players were involved) in the early part (the first two months) of the 2008–9 season. They scored the occurrence, type, and duration of celebratory touching (fist bumps, leaping shoulder bumps, high tens, and so on) that followed a player's making a successful shot. For these same games the researchers also produced ratings using an index of cooperative behaviors, including talking to teammates, passing the ball, and setting screens—that is, behaviors that showed a reliance on teammates, sometimes at the expense of one's own individual performance. To measure individual and team performance over the course of the season, they turned to statistics maintained by the NBA and distributed freely on its Web site.¹⁰ When the data were crunched and the appropriate statistical tests run, there was a clear result: Celebratory touch during games early in the season was associated with higher performance throughout the season for both individual players and teams (figure 1.2).

But might this association come about trivially? For example, what if the best players and teams simply score more often and therefore have more cause to celebrate with touch? That would change the interpretation of the touch-performance correlation. To address this possibility, Kraus and his colleagues applied a statistical correction to adjust for the total numbers of points scored, but the touch-performance correlation still held strongly for both teams and individuals. But what if teams that were predicted at the outset of the season to do well (in polls of coaches or sportscasters) were more optimistic, and it was this factor that led to more celebratory touching and better performance? Again, the predictive power of early-season touch on performance remained after applying a statistical correction based on early-season predictions, as well as another correction based on player status (using salary as a proxy measure).

Finally, when the cooperation scores were analyzed, it emerged that cooperation largely accounts for the relationship between touch and enhanced performance. While investigations of this type cannot prove causality, the correlations in this study strongly indicate that, at least within the context of professional basketball, brief celebratory touch enhances individual and group performance and does so by building cooperation.

But for those of us who don't play in the NBA, what social functions are served by interpersonal touch? Is social touch always intended to foster trust and cooperation? A good way to start approaching these questions is to examine certain of our closest primate cousins—baboons, chimpanzees, bonobos, and vervet monkeys. These species live in large social groups and have many eyes and ears directed at the perimeter of their territory to detect approaching trouble and to keep themselves safe from predators. There is also strength in numbers, for while an adult leopard can almost always prevail in a fight with a single baboon, groups of baboons have been reported to drive leopards up a tree, and even, occasionally, to kill them. Many of these large social units are situated in places with ready access to food. The stability afforded by a low risk from predation and plenty of food gives baboons lots of free time to engage in complex social lives. For instance, Robin Dunbar reports that gelada baboons living in the Ethiopian highlands spend up to 20 percent of their waking hours fussing over the skin and fur of other geladas. That's a huge investment of time in grooming behavior. While grooming is useful to remove dead skin, parasites, tangled hairs, and bits of plant material, the time that gelada baboons (and many other primate species) devote to this task is far out of proportion to the health benefits that accrue from having well-tended skin and fur. The main reason for extended grooming is social, not dermatological (figure 1.3).

Figure 1.3 An adult male gelada baboon (*Theropithecus gelada*) is being groomed by a younger male. This behavior is key to building lasting social bonds and forming alliances.

Gelada live in large troops, typically numbering one hundred to four hundred individuals, but within each troop are many smaller social units: harems, consisting of four or five females, their young offspring, and a single breeding male. When young gelada reach puberty, the males in a harem will depart to join a bachelor group, but the females will remain, assuring that the social core of the harem is a group of related females: mothers, sisters, aunts, and female cousins. These harem females form a loyal and long-lasting coalition that is strengthened and maintained by extensive grooming.¹¹ Their sisterly solidarity is displayed in a number of ways, but none is more amusing than when a member of the coalition is threatened by a domineering male. The single breeding male in the harem must constantly police his females to keep them from having sex with the younger males of the bachelor groups who are always loitering nearby. In addition to scaring off the bachelors, the breeding male will often attempt to intimidate a straying female of his harem with a charge and threat display (panting and teeth grinding). At this point, her relatives race to the rescue, ganging up to chase off the breeding male. But within the female coalition, not all relationships are equal, and some bonds are stronger than others: In an interharem squabble, a female will ally herself with her most avid grooming partner.¹²

In these primate social groups, grooming is as laden with social meaning as choosing their lunch table companions is for high school students. Mothers groom their offspring; mating partners groom each other; friends groom friends, in both male and female pairs. And, just as in high school, the higher-status primates receive more grooming attention than they give. A network of loyalty is created and reinforced by grooming, so coalition members are more likely to come to the aid of one of their group when he or she is confronted by another in the harem or in the larger troop, or even by a predator. Using recording and playback equipment in the field, it has been shown that chimpanzees and macaque monkeys are more likely to respond to a distress call (thereby putting themselves in danger) when the call was recorded from an animal with which they recently groomed.

A young male chimpanzee or baboon may seek to curry favor with the breeding male by grooming him or by establishing a grooming-based alliance with another young male to seek to overthrow the breeding male. If he succeeds in overthrowing the king, it is to his advantage to make a gesture to the deposed monarch to

reduce the chance that he will attack in a bid to regain his former status. If he is clever, he might even get the former king to become an ally in fending off other males during the days of transition. If the deposed king believes that he cannot regain his status, it is to his advantage to reconcile as well, as he would like to remain in the group to protect his last batch of offspring, even if his breeding days are now over. There's a ritual for this reconciliation: The victor presents his rear end to the deposed male, who then reaches through the new monarch's legs to lightly touch his penis. With those formalities concluded, the pair grooms each other like long-lost friends to seal the deal.

So the situation is not dissimilar for human NBA players and certain nonhuman primates like gelada baboons: Social touch tends to reinforce cooperation and loyalty. Human and nonhuman primates alike use grooming and other forms of social touch to soothe, reconcile, form alliances, reward cooperative actions, and reinforce bonds of kinship and friendship. Has this type of behavior appeared only in the primate lineage, or are there traces of it in other animals as well?

There is at least one notable example of social grooming and cooperation in a nonprimate. The common vampire bat, *Desmodus rotundus*, takes wing at night to feed on the blood of living mammals, most commonly horses, burros, cattle, and tapirs. This is their only food source, because their narrow throats cannot accommodate solid food. If the animal they are feeding upon has fur, they will use their canine and cheek teeth to carefully shave away a patch prior to piercing the skin with sharp upper incisors to start bleeding. The bats' saliva contains an anticoagulant compound that keeps the blood flowing for the twenty to thirty minutes of lapping needed to consume a meal. (Sometimes another bat will wait patiently to feed at the same wound.) An adult female vampire bat typically weighs about 40 grams but can consume a blood meal of 20 grams before flapping away, laden and sated. However, vampire bats have a very high metabolism, and if they fail to find a meal on two successive nights, they will lose about 25 percent of their body weight and be near death.

Figure 1.4 A hungry bat solicits regurgitated blood by grooming. The grooming starts with the hungry bat licking the potential donor under her wing (left), and then licking the donor's lips (center). If receptive, the donor responds by regurgitating blood (right). Only bats that are close relatives or exhibit long-term roosting associations provision blood to one another. Illustration by Patricia J. Wynne; used with permission. This drawing first appeared in G. S. Wilkinson, "Food sharing in vampire bats," *Scientific American* 262 (1990): 76–82.

In one part of their range, in northwestern Costa Rica, vampire bats live in hollow trees in groups of eight to twelve. Gerald Wilkinson and his colleagues from the University of Colorado observed these bats in their tree roosts every day for many months.¹³ They found that the animals were more likely to groom each other if they were closely related or if they were frequent roost mates. Grooming also promoted cooperation of a particular kind: A bat that was just groomed was more likely to share a blood meal with its groomer through regurgitation (figure 1.4). In fact, the grooming seemed to function as a type of solicitation for food sharing. By begging food from a roost mate who has just returned from feeding, a bat can fend off starvation for one more night, and so have a chance to find its own blood meal. In the vampire bat world, this is what counts as a win-win deal: I'll groom you, and you'll vomit blood down my throat. Next time, in the spirit of reciprocity, maybe I'll do the same for you.

We've seen a lot of evidence that social touch can promote trust and cooperation. Underlying our interpretation of these findings has been the presumption that all these mammals—geladas and humans and bats alike—shared an early experience of a mother's touch that caused them to associate warm, gentle social touch with safety. What happens when this early maternal experience is lacking?

In the late 1950s Seymour Levine and his coworkers at the Ohio State University Health Center studied the role of early postnatal life on the development of personality, particularly stress responses. They bred Norway rats in the lab, and soon after birth would pick three pups from a litter (which typically consists of ten to twelve pups) and handled them gently for fifteen minutes. This procedure would be repeated every day with the same three pups until they were twenty-one days old. When these handled pups grew into adults, they exhibited a set of positive behavioral traits: They were less fearful, more likely to explore novel environments, and less responsive to stress when compared with their nonhandled littermates. When blood samples were taken from adult rats that had been handled as pups, it was found that brief exposure to stress in adulthood evoked in them a lower secretion of the stress hormones ACTH and corticosterone.¹⁴

These initial studies did not address the means by which handling actually triggered the behavioral and hormonal changes in stress response. Levine suggested that it was not the handling per se that caused the changes but rather the subsequent behavior of the mother rat. When the pups were returned to their home cage after handling, they emitted ultrasonic cries, and in response the mother rat doubled her rate of licking and grooming them. This increased tactile attention persisted throughout the period in which the pups were handled.

While the behavior of mother rats is fascinating for its own sake, we'd ultimately like to know if the lifelong reduction in stress responses of human-handled rat pups is relevant for human development. Interest in this question was sparked by a key set of experiments from a research team at McGill University headed by Michael Meaney. These revealed that if you examine many rat mothers (all Norway rats of the same laboratory strain, called Long-Evans), some lick and groom their pups a lot, while others do less. In fact, the most attentive mothers spent about threefold more time licking and grooming than the least attentive mothers. Furthermore, human handling of the pups could normalize this variation: Following handling, the low licking-grooming mothers increased their pup licking-grooming time to match that of their most attentive peers.¹⁵

When the pups of low licking-grooming mothers grew up, they had impaired spatial learning and more fearful behavior compared to those of high licking-grooming mothers. They were also less likely to explore a new environment or try a new type of food.¹⁶ To be a bit anthropomorphic about it, they were wimps. Their fearful behavior can be related to stress-hormone signaling: Adult rats that were offspring of low licking-grooming mothers had lifelong increases in hormonal responses triggered by stress (figure 1.5).

Figure 1.5 Maternal licking and grooming of newborn rat pups produces lifelong changes in stress hormone signaling. Stress produces a cascade of hormonal responses that begin in a region at the base of the brain called the hypothalamus, which secretes a hormone called corticotropin-releasing hormone (CRH). CRH activates the anterior portion of the pituitary gland, which in turn secretes another hormone, adrenocorticotropic hormone (ACTH), which passes throughout the bloodstream to stimulate the adrenal gland. Then the adrenal gland releases the hormone corticosterone, which has many effects on the body, including regulation of muscular efficiency, metabolism, electrolyte balance, appetite, and vigilance. Corticosterone also binds glucocorticoid receptors in the brain to form a negative feedback loop, suppressing production of CRH. This entire stress-signaling pathway is called the hypothalamic-pituitary adrenal (HPA) axis. Pups of low licking-grooming mothers grow up to have increased levels of ACTH and corticosterone following brief mild stress. (Adult rats were confined to a plastic tube for twenty minutes, following which blood samples were taken.) The brains of these pups also have fewer glucocorticoid receptors available to bind circulating corticosterone, thereby blunting the negative feedback loop and further increasing stress hormone effects.

What conclusion should we take from the correlation between low licking-grooming mothers and increased stress responses in their pups? Does low licking-grooming behavior cause these effects, or is it merely correlated with them? Might low licking-grooming mothers pass these traits on to their pups genetically? And there was another twist in these experiments' findings: In an echo of humans, where poor parenting is often observed across generations, when female pups of low licking-grooming mothers grew up, they were much more likely to become low licking-grooming mothers themselves.

In human behavioral science, disentangling nature-versus-nurture problems often involves studies in which twins are adopted into different families. It's possible to do something similar with rats. Two pups from the litter of a low licking-grooming mother were removed from her within twelve hours of birth, marked with a Sharpie for identification, and then cross-fostered by adding them to the litter of a high licking-grooming mother. When the pups grew up, they had reduced behavioral and hormonal stress responses as compared to their nonadopted siblings. The cross-fostered female pups were also much more likely to grow up to become high licking-grooming mothers themselves. Conversely, pups adopted in the other direction, from high to low licking-grooming mothers, had increased stress responses, and the female pups tended to grow up to become low licking-grooming mothers.¹⁷ These results, together with the beneficial effects of human handling on the pups of low licking-grooming mothers, argue for behavioral rather than genetic transmission of stress reactivity. But the effects of high licking-grooming behavior must somehow be changing the brains and hormonal systems of the pups, so the effects are still fundamentally biological. In fact, we now know some of the biochemical details of how maternal licking-grooming persistently modifies gene expression to underlie behavioral transmission across generations. These "epigenetic signals" are some of the molecular events where nature and nurture meet.¹⁸

If raising pups that are resilient to stress is good, then why don't all the rat mothers engage in lots of licking and grooming, thereby giving their pups an advantage as they make their way in the world? This type of selection can occur even if the mode of transmission is behavioral, not genetic: If the pups of low licking-grooming mothers are at a disadvantage in survival and reproduction, then wouldn't high licking-grooming behavior come to dominate? The answer is complex and not entirely clear. Since wild Norway rats inhabit a great variety of ecological niches, from city dumps to meadows to forests, they must contend with a broad range of ecological demands, including different predators, food sources, and weather. Michael Meaney and his coworkers have suggested that in some ecological niches, like those with scarce food or abundant predators, it might be advantageous to have a high degree of stress reactivity, as imparted by a less-attentive mother rat: When confronted with the constant danger of being eaten or starving, it can be adaptive to be high-strung. One simple idea about how this might come about is the all-too-familiar work/home-life balance: In an echo of human societies, mother rats that have to range far and wide for food leave the nest more often and thereby have less time to lick and groom their pups.

What does the connection between maternal tactile stimulation and stress responses in rats tell us about other species? Let's have a look, first down, and then up, the phylogenetic tree. The tiny soil-dwelling, bacteria-eating roundworm called *C. elegans* is about 1 millimeter long when it reaches adulthood, about three days after hatching. This creature is a favorite of biologists because it is easy to grow in the lab, it has a fast generation time, and it's transparent. We now have a complete map of its adult nervous system, which consists of 302 neurons (compared with about 500 billion in the human brain). Only six of them are touch receptors embedded in the body wall. These touch-sensor neurons provide information that triggers the worm to swim forward or backward, depending upon what it encounters (soil particles, liquid surface tension, another worm). When newly hatched worms were allowed to develop together in groups of thirty to forty in a laboratory dish filled with nutrients, they attained their full length, similar to wild worms collected from soil samples. When these adult, colony-raised worms had their touch receptors stimulated by a tap on the edge of the dish wall, they typically reversed direction and began swimming backward. However, when a worm egg is isolated in a dish, hatches, and grows up in isolation from other worms, it will not attain its

potential mature length and will respond more weakly to taps to the dish wall. The isolated worms tend to just keep swimming straight ahead, as if they do not feel the vibration.

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