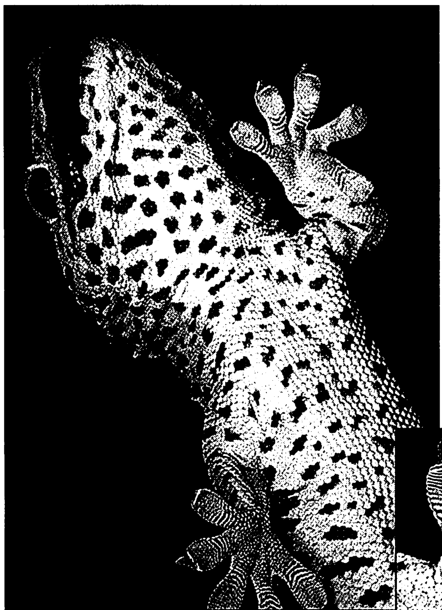
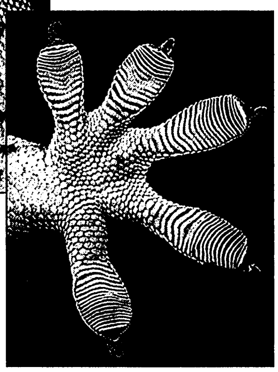
their engineering colleagues hope to design synthetic "footpads" to improve the maneuverability of robots and perhaps to design an entirely new type of adhesive.

As they report in the 8 June issue of *Nature*, weak attractive forces between the 1000 or so split ends on each hair and the ceiling help the gecko grab even the smoothest surface. Such forces are typically generated when two surfaces come very close together. Simply changing the angle of the hairs, called setae, causes these forces to disappear; then the ends let go and the lizard scrambles forward with no hesitation. "It's great to look at how evolution has solved mechanical problems," marvels Bruce Jayne, a functional morphologist at the University of Cincinnati in Ohio.

Gecko toe pads are covered with rows of setae made of keratin, the same protein in human hair and bird feathers. Each seta's curved shaft ends in many hundreds of spatulae, stubby tendrils—too small to see with a regular microscope—with rounded ends.





Magic touch. Thanks to rows of hairs on its toe pads (*right*), this gecko can defy gravity.

To figure out how these hairs might help geckos hang upside down, Autumn tapped the expertise of Berkeley engineer Ronald Fearing and Stanford engineer Thomas Kenny. With the help of a microelectrical mechanical sensor, designed for use with atomic force microscopy, they were able to measure the lateral and perpendicular forces exerted by a single hair that had been removed from a gecko's foot. "The technical difficulty of measuring forces at such a small scale is really significant," points out Jayne. That Autumn and his colleagues succeeded "is really admirable."

At first the hair didn't stick well to the sensor surface. But that changed after the researchers gently pressed the hair into the surface and then began to drag it across and nearly parallel to the sensor—movements that resemble how intact setae work as the gecko puts its foot down. With that motion, "adhesion is rapidly engaged, and that's when we see fairly large forces," Autumn explains.

Previously, Berkeley's Duncan Irschick had measured the overall adhesive forces of a gecko foot. From those, Full and Autumn had calculated the contributions of individual hairs, some 500,000 of which are arrayed in sets of four in a leaflike pattern on the pads. Amazingly, recalls Autumn, "each [hair] was 10 times more adhesive than we would have predicted." One seta is strong enough to hold up an ant, and a million could support a small child.

Autumn and other researchers have ruled out that suction, glue, or even electrostatic forces are responsible. Instead, he and Full think that as the spatulae get close enough to the surface, they generate weak intermolecular forces, akin to van der Waals forces, that sum to guarantee a secure foothold. "Geckos are way overbuilt," explains Anthony Russell, a functional morphologist who has long studied geckos at the University of Calgary. That is how a gecko can cling to ceilings even though just a small fraction of its setae are oriented in an adhesive direction.

Already Full's collaborators have built a robot gecko that scales walls and walks over obstacles. The current model uses pressure-sensitive adhesive and mimics how the gecko uncurls its toes as it puts its foot down and then peels the toes to detach the setae as it walks. These motions "reduce the attachment and detachment forces to almost nothing," enabling the robot (and the gecko) to use up very little energy in the process, says Full. The next step is to outfit the robot with synthetic setae.

The researchers don't expect to find a material that they can split 1000 times, however. Instead, they hope that studies of other lizards and also of kissing bugs, which have setae with few and sometimes only one spatula, will help them design simplified setae that can be manufactured. Eventually, Full and Autumn envision an all-purpose, reusable, gecko tape—one that leaves no residue behind. But Full is not so sure that gecko gloves and climbing shoes will ever be more than a rock climber's fantasy. **–ELIZABETH PENNISI**

NEUROBIOLOGY

Trigger Found for Synapse Formation

Because the ability to form connections between nerve cells is at the heart of all brain function, neurobiologists have looked long and hard for the molecules needed to achieve such biological hardwiring. But they've had little luck in finding the matchmakers of nerve cell connections, called synapses, in the brain—until now, that is.

In today's issue of *Cell*, molecular neurobiologist Tito Serafini and colleagues at the University of California, Berkeley, report that a single protein can apparently trigger synapse formation between brain neurons isolated from mice and grown in culture. The notion that just one molecule can jump-start so critical a process "is a big breakthrough," says molecular and cellular neurobiologist Richard Scheller of Stanford University. If the finding is borne out in living animals, it could provide fresh insights into how the brain is wired during embryonic development and might eventually provide new ways to enhance or at least maintain synapse formation in the brains of patients suffering from neurodegenerative diseases such as Parkinson's or Alzheimer's.

The critical players, according to Serafini's team, are either of two sister proteins called neuroligin 1 and -2. Neurobiologists had suspected that the neuroligins might play some role at the synapse since their discovery about 5 years ago by Thomas Südhof's team at the University of Texas Southwestern Medical Center in Dallas.

At the time, the researchers were studying another set of proteins called neurexins that bind to a toxin from black widow spider venom. Because the neurexins can be produced in literally thousands of variants, investigators thought that the molecules might be involved in building the many different synaptic circuits of the brain—an idea buttressed by Südhof's finding that the proteins act like molecular glue to help cell surfaces adhere to each other. A neurexin, anchored in the surface of the transmitting cell of the synapse, would hook up to a binding partner on the cell that receives the connection, or so the thinking went.

That hypothesis led Südhof to search for candidates that bind to neurexin. In 1995, his team pulled out neuroligin 1, and shortly after that, its relatives neuroligin 2 and -3. Using antibodies, the researchers also showed that neuroligin 1 is located in the synaptic membrane of the receiving neuron. But "the missing link," says Südhof in retrospect, was showing that neuroligins can ac-

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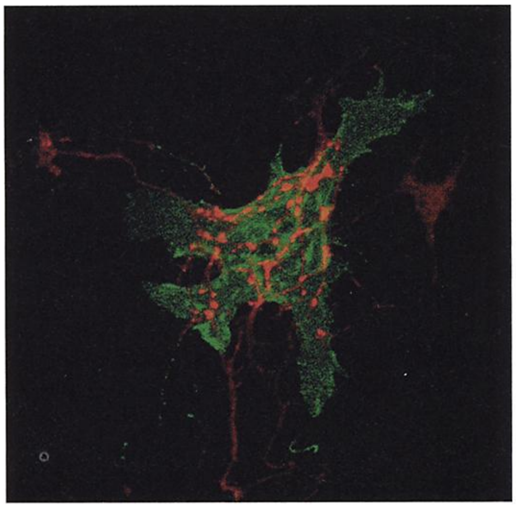

Making contact. As indicated by the red-staining synaptic vesicles, axons from brain neurons begin forming synapses when they contact kidney cells making neuroligin 1 (green stain).

CREDIT: (TOP) P. SCHEIFFELE AND T. SERAFINI

tually initiate synapse formation.

Now, Serafini and his colleagues have done just that. The group, led by postdoc Daniel Emerling, first took mice and dissected out a set of brain neurons called pontine cells. The investigators then teased out a second group of neurons, granule cells, that connect with the pontine neurons in the brain. The researchers found that the two types of neurons form synapses in the petri dish, as they do in the intact brain. They could tell that the neurons were connecting, because they could see clusters of neurotransmitter-containing vesicles forming at the synapse. "We have this [granule] cell type that we know forms synapses very well with the pontine neurons," Serafini says. "The beauty of our system is that we can mine it for the molecules involved in synaptogenesis."

Already the mine is yielding gold. Serafini, postdoc Peter Scheiffele, and their colleagues began by looking at a cadre of candidate genes for synapse formation that are active in granule cells. The researchers genetically engineered those genes, one at a time, into cells that would normally never steer synapse formation, such as human kidney cells or fibroblasts, and then they mixed the modified cells with pontine neurons in their culture system. After a series of genetic duds, the team hit pay dirt with the genes for neuroligin 1 and -2. Kidney cells that expressed either gene could trigger early synapse formation in the pontine neurons just as readily as their normal granule cell partners.

At the outset, says Serafini, his team had hoped for nothing more than some slight changes in the pontine cells that would indicate they were beginning to form connections. "We never expected that a single protein, when expressed in multiple cell types, would drive the entire program of presynaptic development," he says.

Initially, many critics didn't believe the results either. Citing studies showing that plastic beads coated with a substance called polylysine also cause signs of early synapse formation, they argued that the neuroligins' effects might be nonspecific. But Serafini's group went on to address those concerns. For example, in what Serafini calls the "clinching experiment," his team added a neurexin known to bind to neuroligin 1 to the cultured brain neurons.

As hoped, they found a major drop in vesicle clustering—presumably because the neurexin bound to neuroligin 1 and hindered it from acting on the pontine cells. Synapse formation did occur, however, when they used a related neurexin that doesn't bind neuroligin 1. "These are very good controls for specificity," says Scheller, who says he is convinced. "Now this molecule needs to be studied in more detail."

One way of doing that is to knock out the neuroligin genes in mice and see how that affects brain formation and function. Südhof's team already has a neuroligin 1 knockout. Although the rodents appear normal, Serafini notes that another neuroligin could easily pick up the slack for neuroligin 1. So the next step, he says, is to knock out all three neuroligin genes.

Now that the Serafini team's assay has proved its mettle, the researchers plan to use it to look for more genes involved in synapse formation by brain neurons. "We are asking a big question, 'What are the molecules that drive synapse formation in the central nervous system?' " says Serafini. As his team and others continue to "mine" nerve cells for their molecular precious metals, investigators are likely to gain a treasure chest of insights into how the brain develops and functions.

–TRISHA GURA

Trisha Gura is a science writer in Cleveland, Ohio.

GERMAN SCIENCE

Max Planck Charts New Path

Germany's premier basic research organization, the Max Planck Society, released a long-awaited blueprint for change during its annual meeting this week, recommending that the society's nearly 3000 scientists embrace more interdisciplinary and international projects in a range of new research priorities.

In the half-century since Max Planck rose, reconstituted from the ashes of World War II, it has created a loosely knit empire of 78 institutes. Each institute is built around a handful of top researchers who have been given ample resources and considerable independence. Although that formula has produced excellent science—Max Planck scientists have won 10 Nobel Prizes since 1984—some critics contend that it has prevented the society from reacting quickly enough to sudden changes in the scientific landscape and has isolated its researchers from Germany's university system and from colleagues at other institutes (*Science*, 4 June 1999, p. 1595).

Since becoming president of the Munich-based Society 4 years ago, biologist Hubert Markl has sought to address such concerns. He has, for instance, required more frequent outside evaluations of institutes, hired more researchers on short-term contracts, and developed "International Max Planck Research Schools," which starting this fall will offer Ph.D. degrees in cooperation with German universities. The new blueprint, says Markl, will make the institutes "perhaps a little less independent, but much better interconnected with other research groups." According to U.K. Engineering and Physical Sciences Research Chief Richard Brook, who led an international evaluation of Max Planck last year, the recent moves and the new report "indicate that Max Planck is moving in the right direction."

The report, called Max Planck 2000-

A SAMPLING OF MAX PLANCK'S NEW PRIORITIES

"The Molecules of Life"

Structural biology and macromolecules

"From Genes to Organisms"

The Human Genome Project, embryonic development, and cellular regulation

"The Brain"

Information processes, signal transmission, and the molecular basis for cognition, memory, and language

"The Individual and the Environment"

Viruses, gene therapy, and interactions between organisms

"Structure of the World and the Universe"

Astrophysics, plasma physics, and traditional particle physics

"Atoms, Molecules, Materials, and New Technologies"

Smart materials and fast lasers

"Complex Processes and Systems"

Advanced math and applied computer science