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If a person cannot move, talk, or even blink, is it possible to communicate with his **brain**?

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BODY:

One Friday morning last July, Niels Birbaumer, a neuroscientist from the University of Tübingen, in southern Germany, was driven from his hotel in the center of Lima, Peru, to a house protected by a half-dozen armed guards in a gated suburban enclave. He was accompanied by two colleagues—Herta Flor, a professor of neuropsychology, who is his girlfriend, and Thilo Hinterberger, a physicist and computer programmer—and by Jose Luis Palomino, who runs a company in Lima that distributes communication devices for disabled people. With the assurance of a regular visitor to the house, Palomino led the group through a split-level main room, filled with zebra-skin cushions and potted orchids, to a den decorated with sporting trophies, a stuffed deer's head, and a two-foot bottle of Teacher's whiskey. Sliding smoked-glass doors opened onto an L-shaped swimming pool in a bright, spongy lawn. A game of tennis could be heard from the other side of a tall hedge.

Palomino had set up a makeshift laboratory in one corner of the room. Two desks were placed at right angles: a large television monitor was set up on one, and on the other a computer was connected to a small amplifier. The three visitors from Germany plugged in their own laptop computer, and ran tests on the equipment, while politely accepting snacks brought by shy, silent maids. Esteban Ripamonti Aguad, nicknamed Polo, a jumpy, slightly unkempt man of twenty-five, who is the nephew of the owner of the house, came into the room. "We're very happy to have you here," he told Birbaumer, in Spanish. "We've been counting the days." He spoke quickly, underlining his words with whistles and darting hand movements.

Sometime after midday, there was a whisper—"Mr. Elias is coming!"—and through the glass doors one could see a wheelchair being guided very slowly down a ramp by three nurses and a doctor. Polo's uncle, Elias Musiris Chahin—the wealthy owner of a casino and two fabric factories—sat motionless in the chair. He had a scarf over his mouth, another over his head, and blankets covering his body. He was wearing wraparound dark glasses. On his feet were oversized slippers designed to look like leopard's paws, finished with cloth claws.

Once Musiris's procession reached the room, a nurse took off his glasses and scarves, and the extent of his paralysis became apparent. He was breathing with a respirator. His left eye was open only because the eyelid was held in place artificially, and the eyeball was stationary. His mouth, which he cannot move, was open very wide, as if at the midpoint of a yawn. Now and then, a nurse delicately used a damp cotton pad to push her patient's lower eyelid upward, to approximate a blink, and cleared saliva from his mouth with a small suction tube.

To use the blunt medical term, Musiris is "**locked in**": he is unable to communicate with the world, although it is assumed that his senses and his intellect are intact. In 1996, when he was fifty-three years old, Musiris received a diagnosis of a form of amyotrophic lateral sclerosis (A.L.S., or Lou Gehrig's disease), which is incurable. Last winter, he completely lost deliberate movement in his eyes, and, with it, the ability to indicate "yes" and "no." His thoughts became unknowable. Nobody fully **locked in** has ever answered a question.

Musiris's wife, Estrella, joined her husband. She is a tall, broad-shouldered woman in her mid-fifties, with a face dominated by dark-red lips. She made sweeping gestures of welcome, and gave everyone kisses, but she appeared weary in the role of expansive glamour. As Birbaumer later learned, she has been at odds with Musiris's two adult sons from his first marriage, largely over management of his businesses. It was also reported in the Peruvian press that she had argued with her sister-in-law over the origins

of Musiris's condition-Estrella charged the sister-in-law with witchcraft, and was in turn accused of poisoning her husband with chemicals used to cultivate orchids. Meanwhile, Ripamonti, who is her nephew, has embraced the role of dutiful son. A few years ago, he moved in and took charge of Musiris's care. Depending on whom you ask, he either filled a vacuum that the dispute with Musiris's sons had created or executed a coup d'etat. Last year, he started saying that he could communicate with his uncle by reading how his pulse rate changed. He took questions from Musiris's family and business associates, and returned with answers after some hours in private with his uncle. (In the opinion of Birbaumer, who was never allowed to witness the process, the technique was "impossible"-Musiris was on artificial respiration, so he would not have sufficient control of his heart rate-and Ripamonti was guilty of wishful thinking, at best.)

Birbaumer knows that good science can happen in makeshift settings-it can flex in response to place or the impact of a new experimental thought-but for a moment he looked bemused by his surroundings, and by the size of the crowd now growing in the poolside room. He went over to Musiris, and, in a gentle alternative to a handshake, touched the back of his pale hand with three fingers, and spoke to him quietly in English and in broken Spanish. Musiris was then placed at a point about six feet in front of the TV screen. Birbaumer measured his head, and marked positions on his scalp with a red felt-tip pen. He glued electrodes to the spots, and connected them to the amplifier. "Don't try too hard," he said encouragingly to Musiris, who had been introduced to the equipment in the weeks before Birbaumer's arrival. He added, "*Vamos*."

Birbaumer had flown to Lima to attempt the first-ever conversation with a man fully locked into his body. He is a leading figure in a new field of research seeking unconventional lines of command between human **brains** and the world beyond them. **Brain-Computer Interface (B.C.I.)** systems, as they are sometimes known, make an unprecedented proposal: to separate human communication from human muscle, to give thought the power of action. Normally, a **brain** must call on its body to make something-anything-occur. But B.C.I. imagines a short circuit: a **brain** wants something to happen, so it happens, without any need for a mouth or a mouse or a remote control.

B.C.I. research has taken two paths: one proposes to implant electrodes in the **brain** in order to pick up electrical activity there (with one exception-research that began at Emory University, in Atlanta-this has only reached the stage of animal experimentation); the other uses electrodes at the scalp, reading a fuzzier and therefore less useful signal, but without the risks of surgery. The field carries enough promise of dazzling future applications to have created an international network of bad feeling between-and within-these two groups. Birbaumer works in the noninvasive school, as does, most notably, the neuroscientist Jonathan Walpow, who heads the B.C.I. project at the Wadsworth Center of the New York State Department of Health, in Albany. No one doubts the seriousness of Birbaumer's work-he publishes in prestigious journals-but, as he happily acknowledges, its importance lies less at the level of pure scientific breakthrough than in its ability to bring assistance to actual patients. So it's with a little swagger-a defensive arrogance-that Birbaumer calls the equipment that was now hooked up to Musiris's head a Thought Translation Device, or T.T.D.

The nurse who was attending to Musiris's eye stayed at his side, and the rest of the medical team took seats on wicker furniture. Birbaumer sat at the desk. On the monitor in front of Musiris, a white dot began to move across the screen, as if it were tracing a record of seismic activity. Its progress from left to right was steady-an eight-second journey, repeated as soon as it was finished-but it leapt up and down on its vertical axis. Musiris was being shown a part of his electroencephalograph, or EEG, reading, filtered and amplified. The up-and-down movement was a live reflection of his **brain** activity: a reading of the incessant, faint electrical buzz of a hundred trillion synapses; a pattern that differs if one is awake or asleep, calm or panicked. Each time the dot made its left-right journey, one half of the screen was pink-sometimes the top half, sometimes the bottom, in a random sequence. Musiris's task was to change the electricity of his **brain** by changing the thoughts inside it, and to use this to control the ball, to keep it in the half of the screen that was pink-the required direction being reinforced by a recorded voice saying "*arriba*" or "*abajo*," up or down. He was being asked to play a crude video game using only his **brain**.

"To take the light up, maybe try to imagine you're about to fire an arrow-a preparation for action," Birbaumer suggested. "To bring it down, think of something in the future. A projection." Everyone watched the screen. The room was silent except for the whirring noises of Musiris's respiration and waste-removal systems. "*Arriba*," the disembodied voice said, and a light began bouncing its way across the screen. Musiris's audience willed it upward. It stayed up, and Musiris scored a "hit"-that is, the dot spent more than half of its left-to-right journey in the correct half of the screen. A soothing arpeggio chord sounded. There was another "*arriba*," but this time the point of light dipped too much, and there was no rewarding chord. Then "*abajo*," and the light went down-another hit, and so it went on, with almost as many misses as hits. Birbaumer shook his head. A random response would generate a fifty-per-cent score; Musiris was barely managing even this, so no one could confidently regard the hits as deliberate. But the power of placebo is strong, and when the light did obey the instructions-"*abajo*" or "*arriba*"-it was hard not to read this as an act of furious determination, and to follow the light's unsteady movements as one would a dumbbell above the head of a struggling weight lifter.

The experiment ended within an hour. The medical team wheeled Musiris out of the room. Birbaumer, who, from experience,

believes in the importance of reaching a patient before he or she is fully **locked in**, did not look optimistic. "What you haven't learned when you're young, you haven't learned," he said, quietly. "If you haven't learned this before you're **locked in**-" He hesitated before adding, "Maybe we've come too late."

Birbaumer and his colleagues were summoned to lunch. Ceviche and squid had been laid out on a long glass table. Musiris sat at one end of the table, his nurses standing behind him, his open mouth covered by the scarf. (He has not been able to eat since 1998; he is fed liquid nutrients, by tube, into his stomach.) At the other end of the table, directly in his line of sight, a television set showed live security-camera images beamed by microwave from his casino, a few miles away. Estrella Musiris pressed food and wine on her dozen or so guests, who-besides Polo, Palomino, and the scientists-now included Eddie Thornberry, who is Musiris's business manager, and two of Estrella's sisters. One of them, Polo's mother, was wearing a jaunty sailor's hat; the other passed around a set of Polaroid photographs that showed her making big wins on slot machines. (They proved that gambling was financially rewarding, she said.)

Midway through lunch, a servant carried in Estrella's new pet monkey, Lorenzo, who was wearing a red cardigan. Lorenzo was introduced to Birbaumer, then made a shrieking dive for the food, and was taken off to the kitchen. I asked a family friend at the table what he thought Musiris's first words would be if he regained the ability to communicate. He smiled, and said, "Kill the monkey."

When people ask Niels Birbaumer about the mental life of a person locked into his or her body, he often mentions a favorite book, Dalton Trumbo's 1939 novel, "Johnny Got His Gun," which is narrated by an American soldier who wakes up in a hospital bed to discover that his legs, arms, and face have been blown off. The soldier is deaf, dumb, and blind. "He was a dead man with a mind that could still think," Trumbo writes. After several years, the soldier comes to realize that by nodding his head he can tap out messages in Morse code. When military commanders are brought to his bed to hear what he has to say, he asks to become a travelling exhibit, demonstrating the ugliness of war. They reject the idea. They sedate him and leave him. "He was the perfect picture of the future and they were afraid to let anyone see what the future was like."

Birbaumer finds in the **locked-in** syndrome a kind of revolutionary model, with patients oppressed-as he sees it-by neurologists who encourage them to suppose that life on artificial respiration is unlivable; and, on occasion, by family members who discover the advantages of a silent and compliant relative ("the perfect spouse!" he says). He is a liberator, giving speech to the silenced. But Birbaumer is also sometimes mesmerized by the idea of a life of contemplation. "There are days when I think, Oh, I could not stand being **locked in**," he told me last summer, shortly before he flew to Peru. "And then other days when, well, I imagine just being able to think, do nothing but think."

We were in Tübingen, where he runs the university's department of medical psychology. The window of his third-floor office looks past steeply gabled houses toward the River Neckar, where tourists were being punted upstream and down in long, flat boats. Birbaumer, who prefers more dynamic surroundings, and whose own volubility contrasts with the silence of his patients, sat slouched in an armchair, and frequently answered a tiny cell phone in his breast pocket, speaking in German, Italian, and English. There was some sighing and shrugging. Birbaumer, a slight, dark, well-dressed man of fifty-seven, his hair turning gray, devotes much of his day to exasperation at one thing or another: his allegedly bland, overambitious Ph.D. students; the "bullshit" research being done in his field; the "idiots" in Europe and the United States who deny him funding. He is brusque but good company.

In Germany, Birbaumer is a well-known public intellectual who contributes-in an amused, reckless, and sometimes cutting way-to television debates on social and medical matters. His political stance points to a background in the student upheavals of 1968; born in Czechoslovakia and brought up in Austria, Birbaumer is a graduate in psychology from the University of Vienna, and was a professor there until he was fired for agitating against the teaching of an allegedly reactionary senior colleague. He moved into Germany's wrecked postwar scientific community, and was promoted quickly (some think too quickly), becoming a full professor of psychology at Tübingen at the age of twenty-nine. He has been married to the same woman twice, finally separating from her in 1991, and he has an adult son from another relationship. Twelve years ago, he met Herta Flor, who is a leading researcher in the study of pain at the University of Heidelberg. (Her recent experiments showed that a patient's sense of pain can increase threefold when his or her spouse is in the room.) Today, he spends weekdays in Tübingen, then, each weekend, he and Flor drive to a house in northern Italy, where they grow olives and keep pigs. He is a member of what used to be called the Italian Communist Party.

Birbaumer's Ph.D. thesis described how the **brains** of blind people make structural compensation for the loss of sight; he later studied the mental activity of musicians at the moment before they play a note. From early in his career, he has worked with the **brain** waves known as slow cortical potentials (S.C.P.s). In the range of signals that make up the human EEG, S.C.P.s are unusual for occurring over a period of seconds, rather than milliseconds, and they tend to accompany all kinds of human activity; they are not linked to particular motions or emotions. An S.C.P. reading is a fairly reliable indication of general **brain** business. In work that led

to Birbaumer's winning a Leibniz Prize-Germany's best-endowed research award-in 1995, he trained epileptics to fend off an impending seizure by adjusting their S.C.P.s. Birbaumer might have called this process "biofeedback" had the word not been tainted in the nineteen-sixties and seventies by an academic scandal involving the falsification of data, and by "white-robed meditation crap," as he puts it. ("I now call it 'physiological regulation,' " Birbaumer told me. "With this, you impress the medical profession, and the psychologists don't know what you mean. So you don't get into any trouble.") Using feedback carried from electrodes on the scalp, shown in a visual display-a ball rising and falling on a computer monitor-fifty epileptic subjects, all of whom were unresponsive to drug treatments, learned over the course of thirty-five sessions how to send their **brains** into a state of S.C.P. "positivity." When a seizure loomed, they would alter their S.C.P.s. They could think their way out of danger. Birbaumer found that, on average, over the following months, his patients were able to reduce the frequency of their seizures by half; about a third stopped having seizures altogether.

In the late nineteen-eighties and early nineties, the field of B.C.I. was beginning to emerge in Europe and the United States-driven in part by cheap, powerful computers, and by a louder lobby for disabled people. (Much of the neuroscientific knowledge had been in place for a while: electrical **brain** signals were discovered in 1875, and the human EEG was first recorded in 1929.) It was clear to Birbaumer-and others-that if one could change one's S.C.P. reading at will, as his epileptics had done, and if this change could be picked up at the scalp efficiently, and amplified, then this technology might serve as a communication device for people with severe disabilities. The money awarded with the Leibniz Prize-\$1.5 million-gave Birbaumer an opportunity to start a new experiment. In 1995, he began training paralyzed people to write with their **brains**.

The locked-in state can be mistaken for a coma, and a coma can be mistaken for a **locked-in** state. A **locked-in** diagnosis (the term was first used in 1966 by the American neurologists Jerome Posner and Fred Plum) means that although a person has been abandoned by his or her body, the **brain** still functions. The most clear evidence for this is usually some residual voluntary eye movement, a deliberate response to "Blink if you hear me." A comatose patient does not blink; in tests, **locked-in** patients have responded with eye movements that show they have suffered no significant loss of language, memory, or intellectual function. In two rare cases of deliberate total self-paralysis-unconnected experiments in the mid-nineteen-forties to test the possible usefulness of muscle relaxants in surgery-scientists in London and Salt Lake City found that when briefly **locked in** they could see clearly (if someone pulled up one of their eyelids), hear, feel the pain of pinpricks or adhesive strips pulled from their skin, and experience terror ("I felt I was drowning in my own saliva," one later reported).

A French magazine editor, Jean-Dominique Bauby, was almost fully **locked in** after a stroke in 1995, and used his left eyelid to dictate a wry memoir, "The Diving Bell and the Butterfly," published just before his death, in 1997. "I have known gentler awakenings," he wrote. "When I came to that late-January morning, the hospital ophthalmologist was leaning over me and sewing my right eyelid shut with a needle and thread." The book explains the method of its composition. An assistant at Bauby's hospital bedside would run through the alphabet-rearranged according to the frequency of each letter's use in French-and Bauby would blink at the letter he needed, and so describe swooping mental journeys he took to escape from his body:

I reshoot the close-ups for "Touch of Evil." Down at the beach, I rework the dolly shots for "Stagecoach," and offshore I re-create the storm rocking the smugglers of "Moonfleet." . . . I am the hero of Godard's "Pierrot le Fou," my face smeared blue, a garland of dynamite sticks encircling my head.

According to the medical literature (which includes a description of an American man who, at the time of his death, in 1990, had been **locked in** for twenty-seven years), the syndrome has at times been induced by a **brain** tumor, by alcohol abuse, and by a visit to a chiropractor after a car accident. But it is most commonly associated with **brain**-stem strokes (as in Bauby's case), extreme spinal-cord injuries, and neurological diseases like A.L.S. As a result of recent medical progress-in particular, refinements in methods of artificial respiration-the **locked-in** population is now growing. There are no statistics, but Birbaumer guesses that there are twice as many **locked-in** patients in the world as there were ten years ago: he estimates that there are perhaps ten thousand in Germany and twenty-five thousand in the United States. A small proportion of them, perhaps one or two per cent, have survived beyond any lingering eye movement (and beyond any slight sphincter movement, which is often the last control to be lost), to reach a place of complete separation from the world. Among them is Elias Musiris.

The son of Palestinian immigrants, Musiris made his fortune in acrylic and cotton cloth. "He was a successful man, handsome, very sexy," Estrella Musiris told me. "You remember the actor Omar Sharif? This man, he was Omar Sharif." He married his first wife in the late nineteen-sixties. They had two sons, Arturo and Javier, and eventually divorced. He met Estrella in the eighties, but, because his divorce was not final, they did not marry until just before he became ill. "It was love at first sight," she says. "True love, to the end." She and Musiris would sometimes fly to Las Vegas for the weekend. He loved gambling and horse racing. He owned a stable of horses he called Jet Set, and was elected the director of the Jockey Club of Peru. On the walls of a back room in his house, a group of framed photographs show Musiris at the track over two decades, wearing binoculars around his neck, sometimes flanked by

friends in dark glasses and dark shirts, posing with a cup or with a winning horse. Over the years, a little paunch appears under his well-cut jackets, a thin mustache comes and goes. His sons grow up from neat boys in shirts and ties to handsome, privileged teenagers in flared trousers. In later photographs, Estrella is at his side, always tilting her head in a wistful way.

In 1996, when Musiris's A.L.S. was diagnosed, he was optimistic that a treatment might be developed in time to help him; he visited at least ten specialists in the United States. Many A.L.S. patients experience a long period of slowly worsening symptoms, but the disease ambushed Musiris. Within a year, he could no longer walk or talk, and he was already on artificial respiration when, in 1997, he was introduced to Jose Luis Palomino. Then in his mid-thirties, Palomino was a former Navy intelligence officer who had once been active in the government's bloody struggle against the Shining Path guerrilla movement. After a period of self-imposed exile, he returned to Peru, working first as a security consultant and then as a computer-systems adviser specializing in tools for paralyzed people. When they met, Musiris was communicating with an infrared device fixed to his head: by moving his neck, he could direct a point of light on a grid of letters in front of him. "He was losing movement," Palomino told me, remembering his first meetings with Musiris. "I was the only person who told Mr. Elias that there was a strong possibility he would be **locked in**." Musiris brushed his concerns aside. "He'd say, 'Have another coffee, have a dessert.' "

Palomino set up a system incorporating a beam of infrared light pointed at Musiris's chin, and EZ Keys, a word-prediction program that facilitates typing with a single movement. Then his chin movement became unreliable, and Palomino linked EZ Keys to Musiris's static charge, which he could adjust by touching his teeth together. This control was also soon lost. By the end of 2000, Musiris was able to communicate only by glancing to the left or the right. Palomino says that, using this method, "he told me, 'Keep up the communication, whatever it costs. Buy everything. I will try everything.' "

By the beginning of 2001, it was hard to make sense of Musiris's eye movements. By the end of the year, he was fully **locked in**. After reading about Birbaumer on the Internet, Palomino contacted him by e-mail, and last April he and Ripamonti flew to Tübingen for a meeting. Birbaumer is emphatically not in the business of marketing his T.T.D.-he has a leftist's disregard for commerce-but he was struck by Palomino's competence, and was willing to give him a copy of his software, help him buy the hardware, and show him how he was using the combination with patients.

Palomino began training with Musiris, and Birbaumer studied his initial results. They were not spectacular, but because there was some sign of response (and because Birbaumer's brother lives in Paraguay) he agreed to spend three weeks with Musiris in Lima, accepting expenses but no fee. "It's a chance to communicate with a real **locked-in** patient," he said. "Maybe."

When I first met Niels Birbaumer, in 1999, he was four years into the B.C.I. experiment, and seemed confident: he had made progress with several patients at different stages of paralysis, and had recently published an article in the journal *Nature* about his success with Hans-Peter Salzmänn, a former lawyer in his forties who had been disabled by A.L.S. Salzmänn lives in Stuttgart, about half an hour north of Tübingen. Birbaumer met him in 1996, when he was already paralyzed to the point where he controlled only a single muscle under his left eye; with this, he had a Bauby-like means of communication. Birbaumer had found his patient to be smart, methodical, and a little formal-"Prussian," as he puts it. (Even today, Salzmänn, who can still communicate with his face muscle, has never used the more familiar form of "you"-*du*-with Birbaumer.)

Some people find it easier than others to influence their EEG; Birbaumer has discovered no correlation with intelligence or age (although depressives seem to do better than average). Barbara Wilhelm, a research student in Birbaumer's department, told me that she regularly scores a hundred per cent with her S.C.P.s. "To make the ball go up, I think of the 'glory of love,'" she said, with a faint blush. "I just think of that phrase. And, to make it go down, I think of peace and calm, of peace and freedom-the end of the Arab-Israeli conflict." Salzmänn, a former athlete, made the ball rise by imagining himself crouched on the starting line of a race. Salzmänn did not find it easy, but, over time, he improved his technique; he was persistent and highly motivated, and after a year or so he had begun to reach scores of seventy per cent. At this level, he could advance to the next, crucial, stage: a spelling program written in Birbaumer's department. When combined with a monitor, electrodes, and an amplifier, this constituted the T.T.D. Salzmänn saw a screen with half of the alphabet above the horizontal line. Did he want one of these letters? Yes or no? If yes, he had to send the ball up. If he sent the ball down, the other half of the alphabet would appear. Whichever letters were chosen, they would split again into two, and Salzmänn would choose again, and so on until he had reduced the alphabet to a single letter, a process that usually took several minutes. (There was a third screen at each stage, where he could choose to move back to correct an error.)

For the first months, Salzmänn was asked to reproduce letters, or strings of letters, given to him by his trainers. Then came the point when he was invited to spell on his own. Andrea Kubler, a research student then working with Salzmänn, once described to me a landmark day in 1997. Salzmänn produced the letter "A," then "B," "and then 'R.' And I thought he'd been trying to write *aber*-'but'-or *abend*-'evening'-and he'd written the wrong letter, and hadn't managed to delete it." But then he produced "A" and "K." Relatively speaking, the word spilled out of him: "ABRAKADABRA." Soon afterward, Salzmänn wrote a letter to Birbaumer thanking him for

his work and inviting him to a party. The letter was printed in *Nature*.

I visited Salzman a few years ago, and again last July. He lives in a ground-floor apartment in a modern building, and he is assisted at all hours by nurses and by young people who have chosen to do community service rather than enter the military. In a sunny office next to his living room, he was sitting at an angle of about forty-five degrees in a wheelchair, with his head propped up straight; his hands were in his lap. Tubes supplied him with air and food. There was a novel by Elias Canetti on a stand and on the wall a black-and-white photograph of Salzman, taken years before, at a picnic in a field of high grass. He gave me a demonstration of a new program developed by his Tübingen researchers: he could now surf the Internet (or at least a pre-selected part of it) using his **brain**. I watched him visit the site for C. H. Beck, a legal publishing house, and then choose, from the home page of the newspaper *Süddeutsche Zeitung*, a story about the difficulties facing Rudolf Scharping, who was then the German defense minister.

Salzman is still able to make himself understood without B.C.I., if an experienced interpreter looks directly at him from a few inches away, offering him letters. Through a Tübingen research student, Ahmed Karim, Salzman told me that he was glad of the warm weather and of the chance he had that morning to sit outside with his nurses. He told me that his habits of mind had not changed with his illness, but he added, "I have a more vivid imagination when I write, and I think that in general I've become more attentive. I concentrate and I try to memorize more." He said that Bauby's description of the **locked-in** state corresponded to his own experience, although he dislikes the phrase. "As long as I can express myself, I'm not **locked in**," he said.

A few days later, however, when I saw Birbaumer, he seemed to have lost some of his confidence in the experiment. "We're not moving," he said. "Well, we're moving, but we're not moving fast. To make substantial progress, which I think we could do, I would need about ten times the money." In part, his problem lies with the success of the "monkey guys"-his term of half-affectionate disregard for researchers on the invasive side of B.C.I., those who work with implanted electrodes that pick up the **brain's** actual electrical instructions to the body, rather than reading, at the scalp, the by-product of those instructions.

At a B.C.I. conference held last year in Rensselaerville, New York, a researcher of the invasive school was overheard comparing the difference between his research and noninvasive research to jet airplanes and hot-air balloons. A balloon was inarguably colorful and charming, and it worked, but to reach a conference one might prefer a 747. Animal experimenters at Duke University and at Brown University, among other places, are perhaps closer to science's cutting edge than Birbaumer is, and they are more ready to think beyond communication devices to systems of **brain**-controlled motion. Some have formed private companies, and some receive defense funding. ("What the military really wants is a remote-controlled soldier," Birbaumer says.)

Birbaumer takes a kind of moral strength from working with people-a dozen so far-who have immediate communication needs, rather than working with animals, but he is happy to concede that the monkey researchers have begun to produce astonishing results. They have found, for instance, that one can know the intention of a **brain** by keeping track of surprisingly few of its billions of neurons. At Duke University, the Brazilian-born neuroscientist Miguel Nicolelis, who has some of Birbaumer's flamboyant style-his Web site plays "Bim Bom," "Girl from Ipanema," and other Joao Gilberto hits-used techniques developed with John Chapin, now at the State University of New York Health Science Center, to implant hundreds of Teflon-coated microwires, bundled together in groups, into the **brains** of two owl monkeys, in areas of the cortex known to be associated with motor function. A computer algorithm combined the information from the electrodes. Nicolelis trained the monkeys to make particular arm movements, and, over two years, he read and recorded patterns of neuronal firing associated with those movements. He was identifying the neuronal signature of a particular monkey gesture. Two years ago, he was able to use a signal taken directly from the animal's cortex to make a robotic arm simultaneously replicate the monkey's actual arm movement. (And, for good measure, the signal was sent across the Internet, to make a robotic arm move at M.I.T., six hundred miles away.)

Last year, at Brown University, a team lead by John Donoghue, the chairman of the Department of Neuroscience, reported something similar: a monkey first learned to use a joystick to play a video game, while his keepers similarly built up a key-a code book-linking neuronal activity with various actions. Then the joystick was disconnected from the computer. The monkey continued to play the game using only his **brain**.

The clearer signals extracted from the **brain** in these experiments, and others similar to them, may turn out to be suited to the control of wheelchairs or limbs-or even devices of "neurological augmentation" for able-bodied people: speed typing, for example. "Exciting things are going to happen in the next couple of years," Donoghue told me. "We're trying to re-create the nervous system, and I've been shocked how easy it is. You know, it almost seems too good to be true. You have these nights-'How is it so easy to get these ideas out of the **brain** from such small numbers of neurons?' "

Barry Dworkin, a leading neuroscientist and psychologist at Penn State's Hershey Medical Center, says, "There's a technical difference, not a categorical difference, between what Nicolelis and Birbaumer are doing. This is all about information-about how

much information you can extract. No doubt the theoretical capacity of electrodes surgically implanted in the **brain** is vastly greater than Birbaumer's slow potentials, but the electrodes are highly invasive. And it is actually quite hard to extract clean signals from them, and to transform them into real-time movement schemes." He adds, "Our natural speech and motor apparatus works so well it's hard to see the applications for able-bodied people, even with a vastly improved technology. I suppose you could wire people's **brains** together instead of making them meet in a committee room. That might save time. At the moment, for disabled people, there's a lot to be said for Birbaumer's method, if it works. It's not invasive and these people are pretty fragile. Of course, you'll never be able to use it to fly an F-16."

The invasive-technique scientists may have drawn attention and research grants away from Birbaumer, but something else was feeding into his restlessness last summer. It was the nagging possibility that, whatever else he would achieve with the T.T.D., he might never use it to communicate with people fully **locked in** their bodies. The system has not been proved in the environment where it is most needed. Hans-Peter Salzmann still uses his facial muscles for everyday talk: B.C.I. is a secondary tool, for private letters and e-mails generated over weeks and months—a pocket of autonomy in a life that is otherwise entirely collaborative.

Meanwhile, Birbaumer's few fully **locked-in** subjects—those who have no residual facial movement—remained silent. Among them was a woman paralyzed by Guillain-Barre syndrome, a rare neurological condition. A coma test showed that she was "still with us," Birbaumer said—her EEG showed that she took notice, for example, of auditory stimuli—and she seemed at first to be responsive to training, but "now we've seen nothing for more than a year." A patient with hereditary A.L.S. had begun training well before he became **locked in**, but then his wife left him, and he was moved into a nursing home. Now fully **locked in**, he rarely has visitors; his son, who has a fifty-per-cent risk of inheriting the disease, finds it hard to be with him. The patient has stopped responding. "He doesn't want to communicate," Birbaumer said. "He doesn't answer me. I asked him if he wanted to live or not to live. I said, 'You can tell me.' I always say to my patients, 'If you don't want to live, and you have good reasons, I will help you.' But he never said that."

Was it possible that the loss of one's last faint muscle movement somehow eliminated the will to be heard? Birbaumer instinctively resists this idea. He was always upbeat about the potential quality of life of people who are unable to move, and contemptuous of the assumption made by some neurologists that when a patient decides to live beyond the point of artificial respiration he or she enters a zone of hopeless despair. Birbaumer's reading of the literature, and his own research, has suggested to him something more positive. A study done in his department compared the mental life of eighty A.L.S. patients at various stages of the disease, eighty people who had been given a diagnosis of clinical depression, and a sample of those whom Birbaumer calls, with a touch of comic disparagement, "normals." "We found that the A.L.S. patients are significantly more depressed than the normals, but they're significantly less depressed than the depressed; and they're all within the normal range." So, in his opinion, the usual neurological assumption is "just plain bullshit," he said.

But this leaves aside a more focussed question about the mental life of those few people who are, like Elias Musiris, completely **locked in**. "I was once much more secure in the idea that these people really think normally and their inner life is intact," Birbaumer said. "Now I'm not sure."

He had to leave to give a lecture, but, before he went, he said, "You can make yourself die. There are data on that. You can shut down your organism and kill yourself by just doing nothing. In hopeless situations, the immune system falls apart, then you die of an opportunistic disease. You give up."

The Atlantic City casino occupies the first three floors of a gray office building at a key intersection in the prosperous but not pretty Lima neighborhood of Miraflores. When I visited late one night in July, most of the customers were well-dressed middle-aged women; the slot machines produced a dense symphonic din. On a second-floor mezzanine, a little bar had been built underneath a staircase, and the wall behind it was studded with pinpoints of light to resemble a night sky. Elias Musiris was sitting in the dim light, his wheelchair facing a TV monitor that showed security-camera images of the casino, just as in his dining room at home. Estrella was with him. A heartbeat monitor clipped to his earlobe glowed green.

As a healthy man, Musiris spent every night at his casino. He still arrives every evening before midnight, and leaves every morning at dawn. Then he sleeps—the only sign of this is that his eyes move back a little in their sockets—and a nurse watches his face constantly, scanning for signs of crisis. Sometime after midday, he is put into his wheelchair and taken to the dining room. Twice a week, he is washed, and he has a daily massage. A doctor is always on hand. Polo asks questions using his pulse system, and the nurses read to him from the morning newspaper. Then, at night, he is driven again to the casino. "He said he wanted to go to the casino, and for everything to stay the same," Estrella said, when I sat with them. A friend of Musiris's—a fellow textile businessman—came by and kissed him on the forehead. Polo dashed about, now and then changing the image on Musiris's TV screen. I watched him zoom in tightly on a machine where casino guests were making bets on a computer-generated horse race. Bright animated horses

filled Musiris's screen: a silent, security-camera image of a cartoon representation of his favorite sport.

Birbaumer's hotel was directly across the street from the casino. The morning after his first session with Musiris, Birbaumer was sitting in the hotel lobby with Jose Luis Palomino. Birbaumer describes himself as a behaviorist-enjoying the slight datedness of the label-and he makes respectful reference to the work of the late B. F. Skinner, who trained pigeons to peck at a colored plastic disk by rewarding, first, any tiny accidental movement toward the disk, then any closer movement, then actual contact. Skinner called it "shaping"-where a desired form of behavior, even one well outside an animal's usual repertoire, can be fashioned out of a series of small steps taken in the right direction.

"The important part is going to be psychological," Birbaumer said. "The reward. We need maximum reward. Elias is a thinking, feeling person." He glanced across the street. "Can you imagine someone saying, 'If you win on the slot machine, we'll give you the money tomorrow'? We can't just say, 'You will communicate in the future.' That's not enough." (Birbaumer lobbied in his university department for using "sexual reinforcers"-sexual imagery or visits from prostitutes-as a form of "intermittent rewarding stimulus" for some of his patients, who are mostly male. He was voted down by colleagues.)

He and Palomino did not doubt that Musiris had understood them. In a passive "auditory oddball" test, a series of beeps on one note had been played to Musiris, then a beep on another, lower, note. This was repeated. According to his EEG reading, he had registered the different beep, repeatedly, meaning that he had short-term memory and some ability to notice changes in his environment-which is not always true of A.L.S. patients. Another test was also positive.

For Birbaumer and Palomino, then, the issue was will, not skill. How could Musiris be motivated? How could his behavior be "shaped"? "Could we try this?" Palomino asked. He clapped his hands. "Applause. He's an Arab. He likes to have people around him."

"The problem is, human reinforcement might be distracting," said Birbaumer, who had disliked how busy the room had been the previous day. "I was thinking, What's important to him? And it's maybe business. With Salzmann, his control is over us, and the material he keeps secret from us. That's what keeps him alive. We have to think of something that Musiris can take control over."

Back at the house, Musiris was brought into the poolside room and the electrodes were again fixed to his head. "*En sus marcas, listos, ya!*" Palomino said: ready, set, go. The ball of light moved across the screen. To everyone's surprise, Musiris scored a string of hits. The ball seemed to have a new lightness. Musiris managed sixteen hits out of twenty, and the room burst into applause. Polo punched the air with his fist.

But in a trial a few minutes later Musiris scored only seven out of twenty. The following evening, this pattern was repeated: early in the session, he did well, and for a moment he seemed to reveal himself-he had a new, fuller presence in the room. But then he faded, pulled away from his audience by low scores.

Birbaumer had brought a videotape from Germany on which Salzmann was seen slowly spelling out "ELIAS, U CAN DO IT" with the T.T.D.-but Birbaumer did not quite share Salzmann's confidence. Musiris was responding better than any other fully **locked-in** patient Birbaumer had seen. But until Musiris could consistently move the light into the correct half of the screen with at least seventy-five-per-cent accuracy, there would be little point promoting him to the letter-selection program used by Salzmann: the error rate would undermine the system and perhaps crush Musiris's morale.

Daily practice would surely improve the patient's average, but Birbaumer would be in Lima for only three weeks. So while Musiris continued to train in the usual way, with the eventual goal of creating words, Birbaumer and his colleagues began to improvise a simpler system inspired by work he had done years before on lie detection. ("I hated it for ethical reasons, but it was interesting scientifically," he told me.) Musiris would be read a question or a statement. If he sent the ball up, he would be responding "yes"; if he sent the ball down, he would be saying "no." This would be reinforced by a recorded voice saying "*si, si, si, si*" when the ball was above the line, and "*no, no, no, no*" when below. (Birbaumer was increasingly persuaded that Musiris was not seeing clearly, if at all.) As with lie detectors, Musiris would be asked the same thing repeatedly, in both a positive and a negative form: both "I want to go to the casino" and "I don't want to go to the casino." These would be intermixed with control sentences to which the correct response was known: "Lima is the capital of Peru"; "Lima is not the capital of Peru." One could, in theory, spell this way, at an absurdly slow pace. But the system's value was as a form of actual, if crude, communication, and therefore an encouragement. A simple yes-no system would forgive a very modest hit rate. Even a faint bias would become statistically persuasive-statistically unassailable, eventually-given enough repetition. "We can tell his intent from sixty per cent," Birbaumer said. If a tossed coin lands heads up six times out of ten just once, that says nothing; if it happens for a week, then something has been done to the coin-a bias has been proved.

Birbaumer badgered the family for questions that would engage Musiris. Birbaumer also wrote his own list. Although he was keen to ask a question about Elias's feelings for Estrella, he could not see how to express the negative without causing offense: "I love my wife. I hate my wife." "We have to mix the psychology and the mathematics," Birbaumer said. This process of fusion was wearying: he and Herta Flor were also trying to adjust the system to reward even ambiguous responses-and to allow for the fact that Musiris found it easier to take the ball up than down. This put them in frequent conflict with Thilo Hinterberger, who did not want to introduce imprecision into his computer program. In daily arguments over this question, Hinterberger turned from cool calm to red-faced fury in seconds, shouting, "I know what I'm doing!"

For all the conflict, Birbaumer was also stimulated. "I don't usually follow these patients so closely," he said. "You know, I do the business, I get the money, I kick the young people"-his research students-"in the ass, that's my job. I never sit here like this. I don't have time. We should do it like this always. That's the right way to proceed in science. But it's not what's allowed by the system."

On Monday, Birbaumer's fourth day in Lima, they started asking Musiris the yes-or-no questions. "Do you like business?" a recorded voice said. Musiris replied, "*Si, si, si, no, no, si, si, si*"-the ball mostly stayed above the line. "Do you not like business?" "*No, si, no, no, no, no, no.*" The question was asked six times, three times in each form. He gave the same answer five times. Then he was asked another six times: now he liked business three times. Then: "Do you like racehorses? Do you not like racehorses?" "Is your manager Eddie Thornberry?" "Do you like going to the casino?" "Should the casino have two new roulette tables?" At Birbaumer's suggestion, Estrella had taken a place by her husband's side, from where she was saying "*Muy bien, muy bien,*" and blowing him kisses.

Despite the reinforcement-the kisses, the "*si, si, si, si,*" the promise of immediate communication-Musiris's percentages did not show a dramatic rise, and again he was being dragged into the shadows of poor percentages, perhaps by tiredness. But with the new system repetition could squeeze meaning out of a hint. The casino questions, in particular, had begun to generate fairly reliable answers. If one accepted the math, then Musiris did want to go to the casino; and they should buy the new tables.

Musiris left for his night at the Atlantic City. Had there been communication? "We think so, but it's very rudimentary," Birbaumer said. He had seen a breakthrough, of sorts-a dialogue with a fully **locked-in** patient-but he could not be described as upbeat. "We're getting probabilities, but it's not what people like. People don't like statistics." He frowned and shrugged.

Every evening, Musiris came to the den to train. After a week, the yes-or-no system had drawn answers from him that, through repetition, had reached a statistical safety level of more than ninety per cent. Some questions about his domestic arrangements never seemed to engage him: "Do you want to sleep?" "Do you want to stay in this room?" But questions about business reached a level of statistical certainty. "Should we invest in a new textile-dyeing system?" Thornberry asked him. Musiris said "yes," emphatically. "May we sell the old slot machines?" Thornberry wanted to sell them, but Musiris, who was asked more than fifty times, said "no" repeatedly. Thornberry said he would respect that decision. Musiris was beginning to have a deliberate impact on the world without moving a muscle.

He continued to train toward the goal of letter selection. At the end of the second week, Birbaumer presented him with a version of Salzmann's spelling program where the alphabet had been reduced to a handful of letters. Birbaumer gave him a spelling task-two words to copy-but Musiris struggled. At one o'clock in the morning, he had produced nothing. Birbaumer came close to him, and said, "If you spell this correctly now, then you can go to the casino." Over the next twenty minutes, without making an error, Musiris selected "E," "L," "I"-until he had spelled out "ELIAS MUSIRIS." His family shouted, danced, and kissed one another. "He wrote his own name. That was incredible," Birbaumer later remembered. "The family went crazy."

I telephoned Birbaumer a few weeks after he had flown home to Tübingen. "I'm pessimistic about getting him to do real free spelling, using the whole alphabet, and choosing his own words," he said. "But we did communicate with him, and we still are communicating. And I'm more convinced than I was before that the T.T.D. can be useful for people who are completely **locked in**." Birbaumer was thinking about future publication. Musiris was continuing to train with Palomino, who was e-mailing data to Germany each day, although the experiment had been interrupted for several weeks when Lorenzo, Estrella's pet monkey, damaged the amplifier. Lorenzo was now living with neighbors.

While newly optimistic about the possibility of some form of communication with fully **locked-in** people, Birbaumer had revised his sense of the mental lives of these patients. "I have no data on this-it's completely subjective-but now I think that when you become **locked in** you also partially lock yourself in cognitively," he said. Hans-Peter Salzmann will avoid it, perhaps, by training throughout the period during which he becomes fully **locked in**-if that is his fate. But Musiris seemed partially marooned. "Maybe after a while you stop thinking in particular areas," Birbaumer said. "Probably a lot of your inner life becomes empty, and you have

some residual modules in your **brain**. In Elias's case, let's call them the casino module, the factory module, the Estrella module, which can be activated from time to time, but most of the time you're in a **locked-in** state mentally-there's nothing going on in your head anymore. That was my impression with him. In most situations he had just stopped thinking. But this is nothing more than a clinical impression. And you know what that's worth-nothing." He laughed.

Birbaumer was once able to think of his work as an act of subversion; he would introduce into public discourse the voice of a group silenced by neurologists, and they would deliver reports from an unknown place of contemplation where they had been loosened from social norms. "I would have caused a revolution!" he said. "I would have liked that when I was young. I always liked revolutions." The truth was perhaps quieter. "In Elias's situation, I can imagine myself sitting in the chair and thinking a lot, but also not thinking for long periods of time, and maybe communicating with this kind of instrument just now and again," he said. "Rather than our blah blah blah, which we do day and night, which is no use to us. And you see that life comes down to fifty questions! We were wringing our hands-'What can we ask him, what can we ask?' Because in the end what are the crucial questions?" Even in the case of Elias Musiris, a patient with a family, a fortune, and a business empire, there seemed at times to be nothing to say, and no overpowering need for information to pass in either direction. "You ask them, 'Do you want to live? Do you want to die?' After that question, everything else is kind of trivial."

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