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MEDICAL DISPATCH

ROBOTS THAT CARE

Advances in technological therapy.

by Jerome Groopman

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With extroverts, robots can speak forcefully; with introverts, they are more soothing.

Born in Belgrade, in what was then Yugoslavia, Maja Matarić originally wanted to study languages and art. After she and her mother moved to the United States, in 1981, her uncle, who had immigrated some years earlier, pressed her to concentrate on computers. As a graduate student at the Massachusetts Institute of Technology, Matarić wrote software that helped robots to independently navigate around obstacles placed randomly in a room. For her doctoral dissertation, she developed a robotic shepherd capable of corralling a herd of twenty robots.

At the end of her graduate training, Matarić, influenced by her knowledge of cognitive science, became interested in how people could benefit from interacting with robots. Now forty-four and a professor of computer science at the University of Southern California, she has begun working with stroke and Alzheimer's patients and autistic children, searching for a way to make machines that can engage directly with them, encouraging both physical and cognitive rehabilitation.

"We wanted to do something entirely different," Matarić told me. She assembled a team of experts in several disciplines: psychology, mechanical engineering, kinesiology, rehabilitation medicine, and neurology. The team members observed Isaac Asimov's First Law of Robotics: the robot must not injure the patient. They also had to determine what tone of voice was optimal, what type of language the robot should use, how close it should get to the patient—essentially, what kinds of personality and temperament were most effective, and for what kind of patient. The robot would coach the patients orally, rather than physically. (One that physically touched a patient might require approval by the Food and Drug Administration as a device, given the potential safety issues.)

In 2003, Matarić initiated a pilot trial for stroke patients with Carolee Winstein, a professor of biokinesiology and physical therapy at U.S.C. Matarić and Winstein set out to build a robot that would attend a stroke victim in her home, persuading her to employ a weakened limb in her daily activities. Every year, some eight hundred thousand Americans suffer strokes. Currently, Medicare provides limited benefits for rehabilitation, and funding for supervised therapy is especially meagre. A socially assistive robot would be a one-time investment and could be recycled once the person had recovered strength and mobility. (Matarić's research is still in the early stages of testing, and commercial application is years away.)

Winstein believed that people who have a motor disability, like the loss of strength in an arm after a stroke, pursue a path of least resistance. For example, if they want to reach for a cereal box on a shelf after losing force and mobility in their right arm they will simply use their left arm. Such shortcuts undermine the critical period after a stroke when the brain is most plastic and offers the best chance for recovery. And rehabilitative robots tend to retrain the limb in only one motion. "It's as if I wanted to show you how to swing a racquet in tennis," Matarić explained. "I stand behind you and grab your arm and put you through it. But you have to learn to generalize on your own. If you keep doing it with me holding you, you are not actually going to learn. You have to learn how to reach for the cereal on your own, based on your own motivation and your own mode of guiding."

Medical robots are, for the most part, tools to enhance a doctor's or a therapist's techniques—like orthotic devices, which help improve motor control and range of motion after a stroke or other trauma and can offer modified degrees of assistance as the patient recovers. Allison Okamura, a professor of mechanical engineering at Johns Hopkins in Baltimore, Maryland, is studying, along with a team of neuroscientists, the potential applications of a robotic exoskeleton for patients who have suffered damage to the cerebellum. Such patients have trouble controlling their limbs; the exoskeleton robot would encase their arms and coördinate physical movements. The patient could use the robot until he recovered, or perhaps for the rest of his life, if the deficit persisted.

Matarić's work on social robots, however, must address a higher level of complexity. "The challenge is to have cognitive models built into the robots, so the robot understands how to motivate people," Okamura says. "In my work, we just have to move patients in the right way. What we are doing is still quite hard, but what Matarić is trying to do is much harder."

Rodney Brooks, Matarić's mentor at M.I.T. and a former director of its artificial-intelligence program, is a pioneer in designing robots that function independently in unstructured environments. (He helped found iRobot, the company that developed the Roomba vacuum cleaner and other devices.) "Maja's work with me was inspired by termites," he told me, which are able to build complex structures. "Her work was to develop simple rules for robots that, like termites, have no cognition and when alone can't accomplish much," Brooks explained. Matarić's current work on socially assistive robots, in which humans and machines work together, strikes Brooks as a natural evolution from her graduate work. He noted, "She is taking a lead in moving to an imaginative level."

In a pilot trial involving six stroke patients, Matarić's team found that a patient was more apt to take up the task at hand when encouraged by the robot than when he was alone and unprompted. Related studies have also shown that the patient is more responsive when the robot is in the room, rather than when it is shown to the patient on a computer screen or presented in a simulated way, using a three-dimensional virtual robot.

A woman I will call Mary, a schoolteacher in Los Angeles, suffered a stroke in 2001, when she was forty-six. She spent six months working with a physical therapist at the U.S.C. Medical Center to regain strength in her weakened right arm and leg, before taking part in Matarić's study. I watched a videotape of her session with Matarić. Mary, who was dressed in a white blouse and dark slacks, shuffled slowly to a desk stacked with magazines. There was a shelf nearby, set above shoulder level. She looked at the robot, several feet away, and waved to it. "Come over here," she said warmly.

The robot, which was three feet high and looked a little like R2-D2, in "Star Wars," scooted close to her and stopped. "Very good," Mary said.

Set on a mobile base with rotary wheels, the robot could turn in any direction and move around the room, guided by sonar. It tracked Mary's movement with a scanning laser range finder; a pan-tilt-zoom camera allowed it to look at Mary, turn away, or shake its head. A speaker, embedded in the robot's side, produced prerecorded speech and sound effects.

Glancing at the robot, Mary lifted a magazine from the top of the pile and guided it into a rack on top of the shelf. As soon as the magazine was in place, the robot emitted a beep. During the next few minutes, Mary moved each magazine, one by one, to the rack. Gradually, she increased her pace, and the beeps from the robot came faster. Mary began to laugh.

She turned and looked squarely at the robot. With a sly smile, she moved her weak arm toward the remaining magazines on the desk and mimed putting one into the rack. She then stuck her tongue out at the machine.

Matarić said, "She is cheating. She is totally thrilled, because she thinks she cheated the robot." The robot, though, was on to the game. A reflective white band that Mary wore on her leg allowed the robot to follow her movements. A thin motion sensor attached to her sleeve transmitted Mary's gestures to the robot, so that it knew almost instantly whether she was raising her arm and in what motion. A sensor in the rack signalled the robot when a magazine was properly placed, and the robot communicated with Mary only when she performed the task correctly.

Although the task lasted about an hour, the novelty of the interaction did not seem to wane. In a debriefing after the study, Mary said, "When I'm at home, my husband is useless. He just says, 'Do it.' I much prefer the robot to my husband."

But not all the patients in the pilot study were won over. In a video that I watched with Matarić, a trim man in his fifties took one magazine, and then another, and placed each in the rack. He made limited eye contact with the robot. The robot tried to encourage him. “Keep going,” it said. “Very good, keep going.” The man didn’t respond. “Does he look like he is having fun?” Matarić asked. “Never a smile, never a word to the robot.” When the task was over, he walked away.

Matarić concluded that, as with human caregivers, temperament would be a key factor. The robots would need to be able to judge whether a patient was introverted or extroverted, and know how to respond in the appropriate manner.

To test their theory, Matarić and her team categorized the personalities of healthy volunteers, using the Eysenck Personality Questionnaire, and observed their responses to robots that were programmed to behave as introverts or extroverts. A robot’s degree of sociability was defined by how far it positioned itself from the patient, the speed of its movements, and its type of communication. For people who were more extroverted, Matarić programmed the robot to move close. “We are not talking sociopathically close, because we always maintain three to four feet of safety distance between the user and the robot,” she explained. “But, with the extroverted robots, they move into your area, and talk with a slightly higher pitch, more words per unit time, and they say things that are more forceful, like ‘Come on, you can do three more. I know you can do better than that.’ ” The more introverted robots were programmed to stay farther away from the user, to gesticulate less, and to speak with a slightly lower pitch and at a slower tempo. “You don’t want to make the introversion glaring,” Matarić said. The introverted robots also said more soothing things and offered more praise.

Nineteen subjects participated—seven on the introverted end of the scale and twelve on the extroverted end. The volunteers were instructed to perform tasks with their non-dominant hand, to resemble the impairment of a stroke. They drew lines on paper placed on an easel, lifted books from the desktop to the shelf, moved pencils from one bin to another, and turned the pages of a newspaper. The objective measure was how much time was spent on each task. “When the subject and the robot are matched, people perform significantly longer on a task,” Matarić said. “So if you are an extrovert I’ll give you an extrovert robot.” Of course, Matarić noted, a stroke patient’s temperament may change over time. As he begins to recover, he may regain a livelier demeanor.

So Matarić and her co-workers developed an algorithm for learned behavior, with the robot adapting to match the participant’s preferences in terms of therapy style, interaction distance, and speed of movement. The robot was able to gauge the subject’s time and success in performing the assigned task and then to modify its behavior accordingly. “We actually had the robot slightly shift its personality, gradually, while interacting with the user,” Matarić said. This capacity to adapt is called “machine learning.” The programming has to be carefully done, she explained, because “you don’t want the robot to schizophrenically suddenly change. You don’t want it to become a dictator all of a sudden, because that breaks the whole engagement.” She went on, “But over time, with slow changes, you end up somewhere that’s quite different from where you started. The notion of social engagement is to keep people doing something even if they really don’t want to do it. It may be painful, it may be boring, it may remind them of their disability, which is frustrating. But we know you need to not be in your comfort zone, because if you are fully comfortable, then you are not pushing yourself enough.”

Human coaches, Matarić explained, might read a person’s facial expression, but even an intelligent robot has difficulty interpreting nuances in lighting and appearance. Also, patients may mask their feelings. To overcome these problems, Matarić’s team placed galvanic sensors on a band on the subject’s upper arm, whose readings Matarić believes will provide the robot with sufficient information about whether a patient is being challenged or becoming frustrated. (Other physiological changes, such as sweating from vigorous exercise, could affect the reading.) In a test requiring subjects to move a ring around a maze without hitting the boundary, during which the robot would announce points lost when they made mistakes, Matarić’s team was able to predict with nearly ninety-per-cent accuracy when people were about to quit. “So you know that they were not happy about something,” Matarić explained. “And then you can switch modes, do something else, or praise them. The idea is for the robot to have general understanding.” The system also allows for greater privacy than a camera device. “I don’t want to have to worry about whether I’m dressed when the robot is in the room,” Matarić said.

In a new trial, with twelve stroke patients and six healthy controls, launched at U.S.C. in October, Matarić is trying to customize robotic behavior to assess how much variety patients want. “Clearly, some people need steady repetition,” Matarić said. “But others, like Mary, just want to discover new things. I mean, she is not compliant. This issue of compliance is huge. How do you get people to do what they need to do when most people don’t want to do it? And then you have certain personalities that are extremely prone to not wanting to do it.” A former teacher, Mary “would probably never tolerate cheating, or miming a task, and certainly not tolerate sticking out her tongue at an instructor,” Matarić noted. But her efforts to outsmart the robot may have represented an attempt to restore the sense of self lost as a result of her stroke. “This is something that we are thinking about as another dimension of the robot-human interaction: how much authority should the robot have?” Patients don’t want to be entirely subservient to the robot, Matarić said. “Disabled people don’t want to give up what’s remaining to them.”

Gerontologists have observed that, when fish tanks are introduced into a nursing home, residents congregate to watch the fish; this not only sparks more conversation among the residents but also encourages healthier eating. Robotic pets, which do not require the caretaking of a real pet, have also been shown to increase socializing and reduce stress. Matarić hoped to produce a similar effect by providing humanlike interaction through a robot, focussing on elderly people who have been given a diagnosis of mild to moderate Alzheimer's disease. In a video taken at an elder-care facility in Silverado, California, a robot sang "Singin' in the Rain" to a frail-looking woman with silver-gray hair who sat beside it. The game was Name That Tune: the patient would press one of three buttons to identify the song. (The robot might offer hints, like "the weather.") After a few moments, the woman started to sing along. Then she pressed the first button, and the robot exclaimed, "Right button!" It made a motion to clap its hands. Later, a similar task was done using a computer screen instead of the robot; the woman would not look at the screen, and took much longer to identify the song and to push the right button.

At the beginning of the study, the Alzheimer's patients tended to avoid looking directly at the robot, and offered less spontaneous speech. Over the course of the study, which lasted six months, the patients showed significant improvement. They increased their focus and more often pressed the right button. "They improved their performance within the pretty small envelope of what's possible," Matarić said. "And there was no progress like that with the computer screen. It's counterintuitive, because you would think that if you give very old people robots they might be put off by how alien they are. But it actually seems to be less alien than the computer."

Matarić has begun a new study, expected to last through the year, using a robot that plays Simon Says, and the Robert Wood Johnson Foundation has recently given her funding to do a large study with seventy people, including healthy adults and elderly patients. The study will compare socially assistive robots with computers in tasks that enhance learning and may improve brain function.

The testing in Silverado also revealed that some of the elderly and mildly demented patients projected their emotions onto the robot. "One woman actually refers to it as a grandchild," Matarić said. "Others said that they would like to arrange their schedule around singing to the robot, and, frankly, there was not that much schedule to arrange. But it's the high point of their day." During the six months, the robots became part of the patients' lives. "One woman spun quite a yarn," Matarić said. "They had whole internal stories about how the robot fit into their lives, however unreal those stories may be."

Three years ago, CosmoBot, a robot produced by AnthroTronix, a Maryland-based startup, was introduced at the Neurodevelopmental Diagnostic Center for Young Children, in Crofton, Maryland, serving children with autism and with genetic disorders that affect the nervous system. CosmoBot is a Wizard of Oz robot that is externally controlled by a therapist; it has an elliptical head and the ability to swivel, in order to change its gaze. "The robot performs a motor action in a highly predictable way, repeating exactly the same sequence over and over," Carole Samango-Sprouse, the director of the center, explained. The robot is captivating and toylike, she said, and less stressful than human demonstration, in which minor variations can seem extreme and disturbing for a child with learning or behavioral difficulties. In addition, the robot can change a sequence but still make it appear predictable. More than thirty children have worked with the robot, and the initial observations, presented at an assistive-technology conference in January, have shown improvements not only in motor ability but also in social skills. "These children are encased in their own disability," Samango-Sprouse said. "The robot gave us a really nice bridge to build imitation for motor development and then speech and then social engagement."

One of those children was Kevin Fitzgerald, a six-year-old who lives outside Baltimore. His mother, Patty, noted that Kevin experienced delays in learning to roll over, sit up, and walk. "Everything that we teach him, we have to teach him step by step," she said. Kevin has been given a diagnosis of generalized dyspraxia, a disorder characterized by weakness and poor coördination, particularly of his arms and mouth. His social and emotional functioning is also severely impaired. "He tends to go to the extremes," Patty told me. "If you are sitting and playing and someone comes up and takes the toy away, he can have a complete meltdown, whereas another kid might just get mad. And at the other extreme, when he gets happy, he will be giggling and laughing and his arms swing and his whole body is moving." Kevin also had great difficulty with speech, often simply grunting or screaming. "We were mostly communicating through sign language at that time," Patty told me. "But it was really limited success. He got frustrated and didn't want to do that. He wanted to speak."

In November, 2007, she brought him to the center in Crofton. The therapist at the center placed a glove on Kevin's hand so that he could wirelessly direct CosmoBot around the room by making gestures to the right or the left. "I think it put Kevin in the instructor role, which he never was in," his mother said. "He always was the one having to listen to whatever people told him to do, constantly, all day long—No, Kevin, don't touch that. Kevin, be careful. Kevin, slow down."

Whenever Kevin accomplished a task, the therapist remotely controlling CosmoBot would have it clap its hands and say, "Good job." Eventually, Kevin was able to navigate the robot through a maze. "CosmoBot is calm and consistent," Patty said.

"He is not another child who gets upset about something or even too excited. . . . And the robot can do things ten times over exactly the same way without getting frustrated." Patty told me that Kevin's speech and behavior have markedly improved since he began working with CosmoBot.

The C.E.O. of AnthroTronix is Corinna Lathan, who, like Maja Matarić, earned a Ph.D. at M.I.T. The company has struggled to get the financial backing that would allow it to conduct studies and distribute the CosmoBot. Although it has received some support from the National Science Foundation and the National Institutes of Health, she said, robotics "has never been hot in the investment community, and I totally get why: it's hardware, and investing in hardware has a low return on investment when you are comparing it to Internet-based or software-based products."

AnthroTronix is now shifting away from using CosmoBot as a therapeutic device and recently received a grant from the Department of Education. A Phase II study in Minnesota, run by the Mayo Clinic with funds from the National Institutes of Health, is pilot-testing CosmoBot for children with individualized education plans that require physical therapy, including those with neurodevelopmental disorders or cerebral palsy. The Individuals with Disabilities Education Act requires schools to provide assistive technology to children, and Lathan hopes that "there will be a little more open-mindedness."

David Feil-Seifer, a graduate student in Matarić's laboratory, is working to develop a socially assistive robot for children with autism without the need for a Wizard of Oz setup. Feil-Seifer and Matarić have already conducted pilot studies with eleven children who are cared for at the Children's Hospital of Los Angeles. Peter Mundy, a professor of psychology and education at the University of California at Davis and an expert on autism, helped design the study. Mundy was one of the researchers who first identified a disturbance in "joint attention"—the ability to share interests and information with other individuals—which occurs in many children with autistic-spectrum disorders. Mundy hypothesized that the robot "would be a central medium to build joint attention," since many children with autism are able to focus on objects in a way that they are unable to do with other people. FeilSeifer and Mundy hoped to measure improvement by whether a child with autism could shift his attention from the robot to a parent or a therapist, and then back to the robot.

Feil-Seifer and I watched a series of videotapes from these initial experiments. The robot, which was programmed to use hand gestures, waved a boy toward it. As the child drew closer, the robot emitted a series of soft beeps, and nodded its head. But the boy retreated. "Look at how the robot expresses disappointment when the child moves away," Feil-Seifer said. The robot had put its head down, as if discouraged, and then waved again in a gesture meant to encourage the child to come closer.

The robot had a bubble blower in its lower torso. On its shoulders were two large buttons, one red and one green. The robot first spontaneously blew bubbles, and then stopped. The mother encouraged her son to approach the robot and press a button. When he did, it produced streams of bubbles. The boy laughed and looked squarely at his mother.

"You see how he is interacting," Feil-Seifer said. "He is both physically interacting with the robot and also looking back at his mom, talking to his mom, not just talking to the robot. And he is exploring the robot, trying to figure out how he can do things. This is very encouraging to us. And it's in contrast to what we are going to see next."

The second video showed the robot with the boy at another session. This time, when he pressed a button on the robot's shoulder, nothing happened. A short time later, bubbles spontaneously flowed from the robot, and then shut off.

When the robot blew bubbles randomly, the boy began to play with the bubbles. He touched the button again, but nothing happened. He immediately withdrew from the robot, placed his back against the wall, and looked down at the floor, ignoring both his mother and the machine.

Feil-Seifer, with Matarić's guidance, is trying to figure out how to design robot behavior that meshes with the child's expectations about the robot. He further tested random versus contingent bubble blowing in another child with autism who had been evaluated as "high functioning." When the robot responded with bubbles to the child's pressing the button, the boy became deeply absorbed, standing close to it, and looking repeatedly at his mother with a smile. But, during another session, when the robot began randomly blowing bubbles he moved off to the side. "He doesn't try again in front of it," Feil-Seifer said. "He is not trying to socially interact with it at all. He is really disappointed." At the end of the session, the child turned to his mother and said, "I think the robot is learning-disabled."

The "uncanny valley" effect, a term coined by the Japanese roboticist Masahiro Mori in 1970, was a serious consideration for Matarić's team when they were developing these social robots. Mori's hypothesis, that there is a moment at which familiarity becomes unease as a robot becomes more humanlike, has been linked to Sigmund Freud's 1919 essay "Das Unheimliche" ("The Uncanny"), which explores the effect of objects that seem both familiar and alien, causing simultaneous attraction and repulsion. If the robot looks completely like a machine, with no anthropomorphic characteristics, there is limited empathic engagement. But, if it looks too human, people quickly become uneasy and even disgusted.

David Hanson, who trained at the Rhode Island School of Design and once worked at Disney's MAPO (short for Mary

Poppins) lab, crafts strikingly realistic heads for his robots, with lifelike skin made of a material called Frubber. He has developed robots that have speech-recognition capability and are programmed to respond; his Philip K. Dick robot, based on the science-fiction writer, incorporates thousands of words from Dick's oeuvre and interviews. (Other models include Joey Chaos, who has a snarky attitude; Albert Hubo, made in the likeness of Einstein; and Vera, a "humanlike robot of universal beauty," modelled on the bust of Nefertiti in Berlin's Neues Museum.) Hanson believes that his creations give "the illusion of a soul in the machine," and that eventually his robots "will evolve into socially intelligent beings, capable of love and earning a place in the extended human family."

Most scientists in the field of robotics—including Matarić—believe that the uncanny-valley effect is real, and should be respected. For that reason, Matarić's robots all share features that humans can relate to but that are also distinctly machinelike. For some critics, however, the very premise of social robots appears flawed, and even dangerous. Sherry Turkle, a professor at M.I.T. who has expertise in psychology and sociology, is concerned about both the stated need for robots and, she says, the risks they pose to "the most vulnerable populations—children and elders." Her concerns aren't confined to humanoid robots, like Hanson's, but extend even to those that are clearly machines. "The simplicity of the robot is not the point," she said. "The paradox is that you can get more attachment with less, so the more simple robots can pose even greater dangers."

Thirty years ago, Turkle began studying the impact of sophisticated technologies, including virtual-reality computer games and robots, on emotional development in children and social relationships among adults. "I am not a Luddite," Turkle said. "But there is no upside to being socialized by a robot." Based on her observation of groups of different ages, Turkle has found that "children and the elderly start to relate to the object as a person. They begin to love it, and nurture it, and feel they have to attend to the robot's inner state." With this attachment and projection of their emotions, Turkle says, people begin to seek reciprocity, wanting the robot to care for them. "We were wired through evolution to feel that when something looks us in the eye, then someone is at home in it."

Robots, Turkle argues, risk distorting the meaning of relationships, the bonds of love, and the types of emotional accommodation required to form authentic human attachments. She questions whether robots are necessary in the settings that Matarić and others are exploring. "What human purposes are served by fostering these attachments?" Turkle asks. "The benefits have to be extraordinary, and, as far as I'm concerned, the jury is still out. You are dealing in deception about what is fundamentally human—the nature of conversation, attachment, nurturing." She is not convinced that the elderly in nursing homes need robots. "Why not people?" And she is not convinced that robots serve as a bridge for autistic children to learn how to connect with family or friends. Only a small number of children have participated in studies, Turkle notes, and there are no data on long-term effects. And while Turkle does not doubt the good intentions of roboticists like Matarić, she points out that the direction, if not the purpose, of their research is to produce a robot that can function independently of a human therapist. "Is it something a robot can really do that a person cannot?" she asks. "Why is a machine touching something in us that is so appealing?"

In Turkle's interviews with people who interact with robots, she has been struck by how many state that they "can't trust people," and that the robot offers a safe and secure relationship. "We need to really think through now where we are headed with social robots, whether we really don't have people for these jobs." The idea that robots will teach people to relate to others, she says, is as fallacious as the argument that e-mail facilitates telephone conversation and then direct discussions. "People lock into the place where they can hide and feel safe," she said. "And while we know this with computers, we seem ready to move ahead with robots that are designed to perform in a way so that a person believes there is somebody at home. If the patient actually learns something about himself, then I could imagine that these objects would be valuable. But that is not proven. Right now, it's a giant social experiment with real risks."

Matarić is aware that intelligent social robots raise worries about emotional impact. She and her team, in the course of their research, have asked, What happens if a robot breaks down, or is taken away, after the person invests the robot with the qualities of a grandchild or a companion? What if a user begins to treat the robot like a slave, and then extends this destructive behavior to a family member or a friend? And, even if the machines are unaware of morality, robots must be prepared to act ethically. Her team is trying to envisage future ethical dilemmas. For example, if a patient being assisted suddenly needs emergency attention, what is the robot's responsibility? Matarić is trying to create independent robots that are able to perform the tasks of human caregivers and are capable of displaying empathy toward patients. "But robotic interaction should not replace human interaction," she said. "It should only improve it." ♦

ILLUSTRATION: BOB STAAKE